Alfvénic fluctuations, velocity spikes, and predicting observations close to the Sun

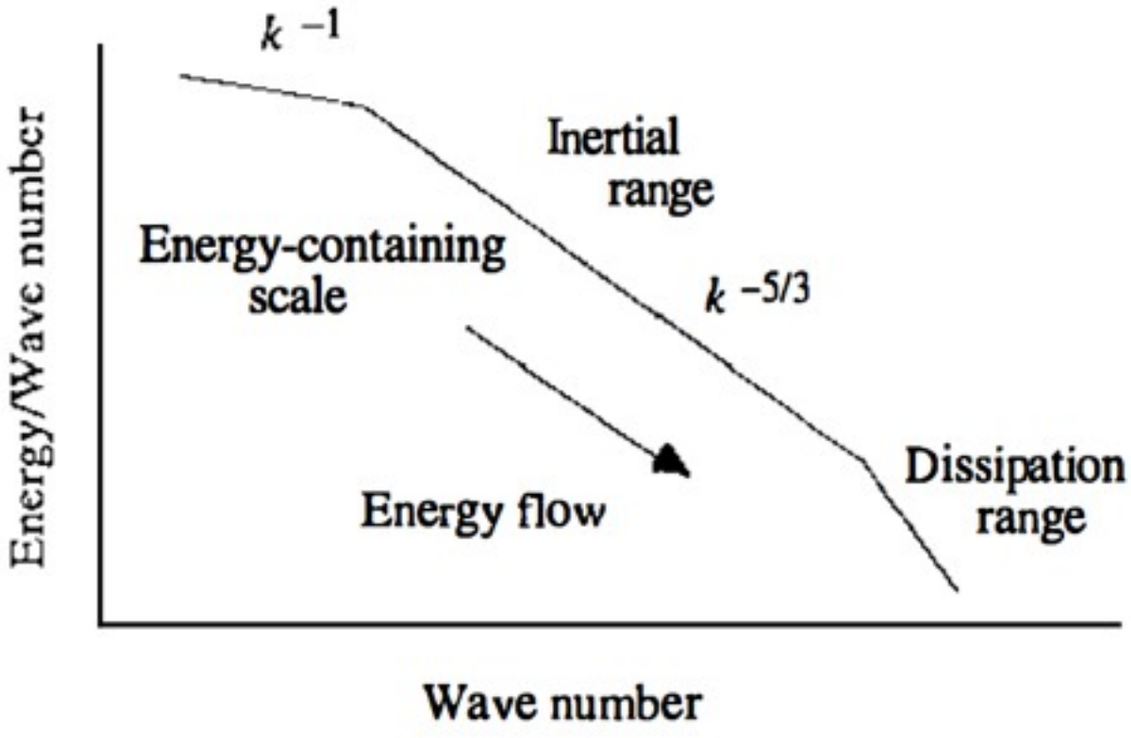
or

How Helios still surprises us after 40 years!

Lorenzo Matteini
Imperial College London

In collaboration with T. Horbury,
M. Neugebauer, and B. Goldstein

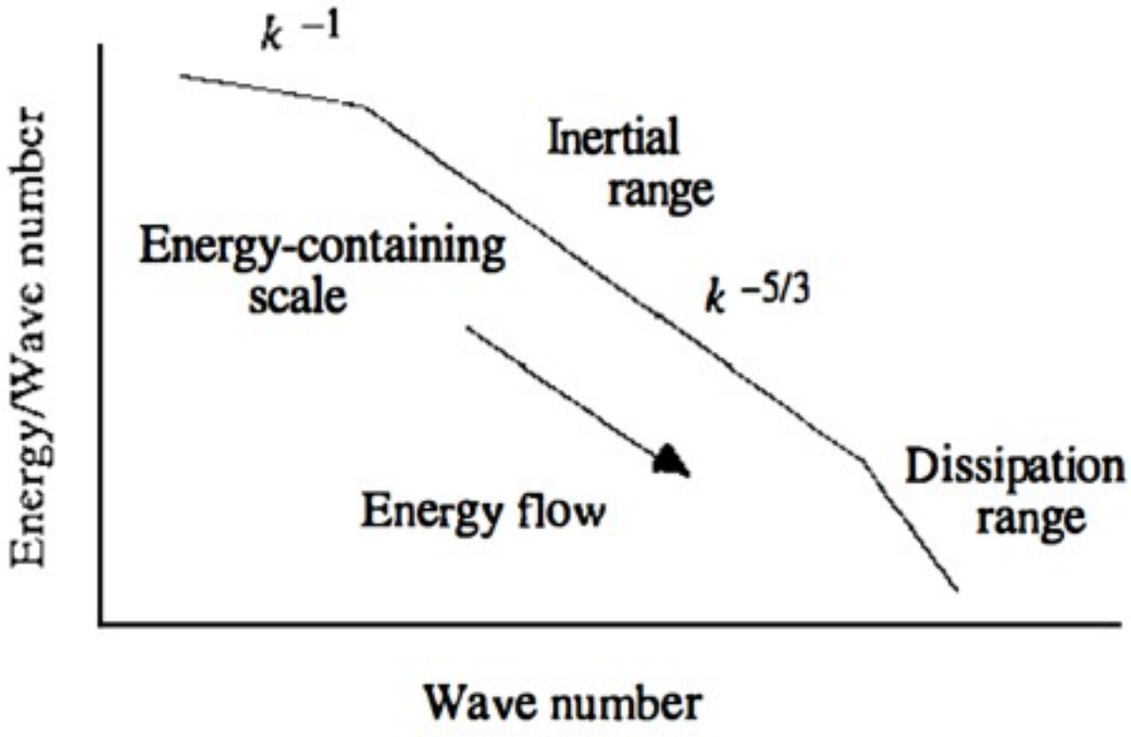
Magnetic field fluctuations



Fluctuations: dB/B~1

Large variations in the direction of the local magnetic field

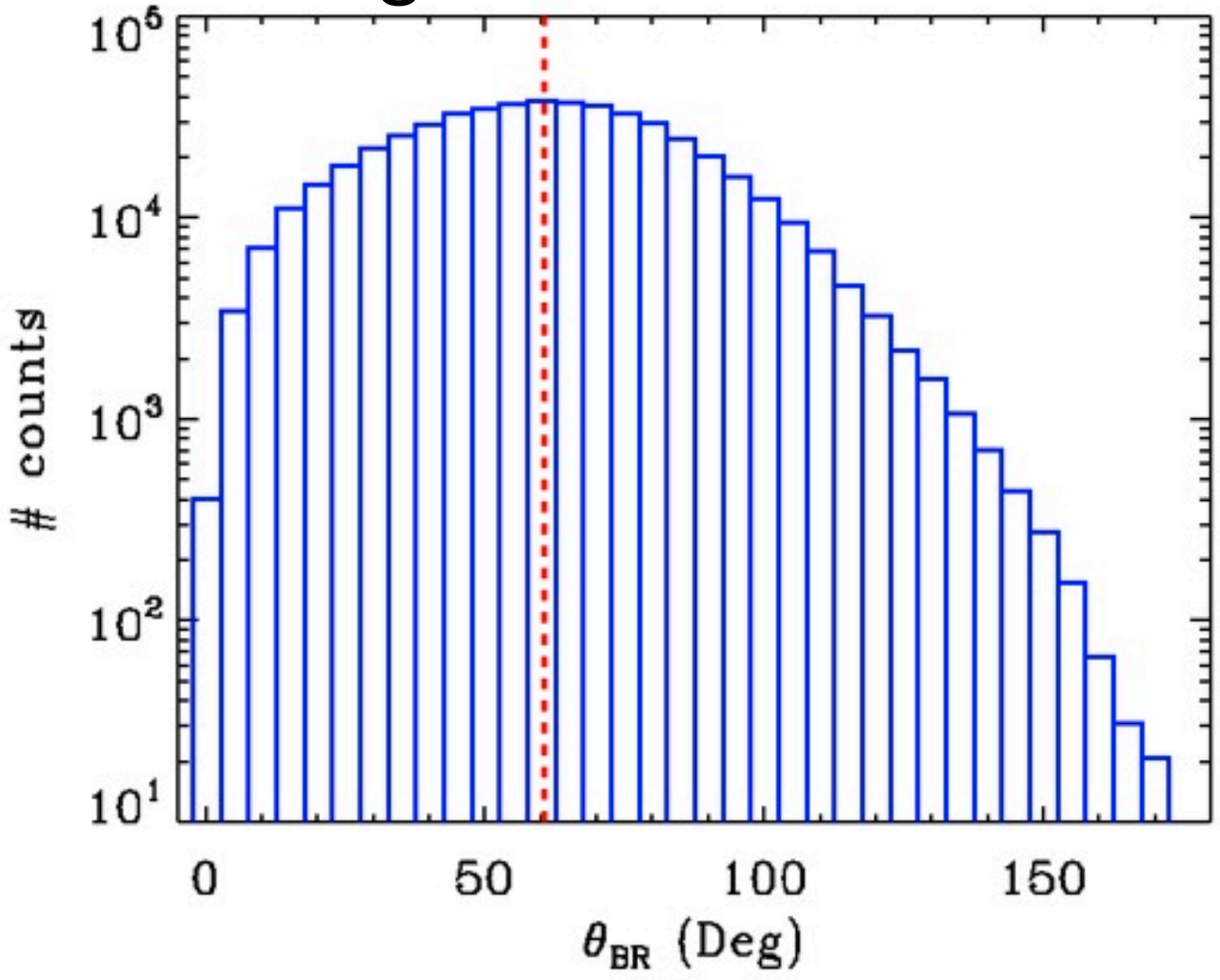
Magnetic field fluctuations



Fluctuations: dB/B~1

Large variations in the direction of the local magnetic field

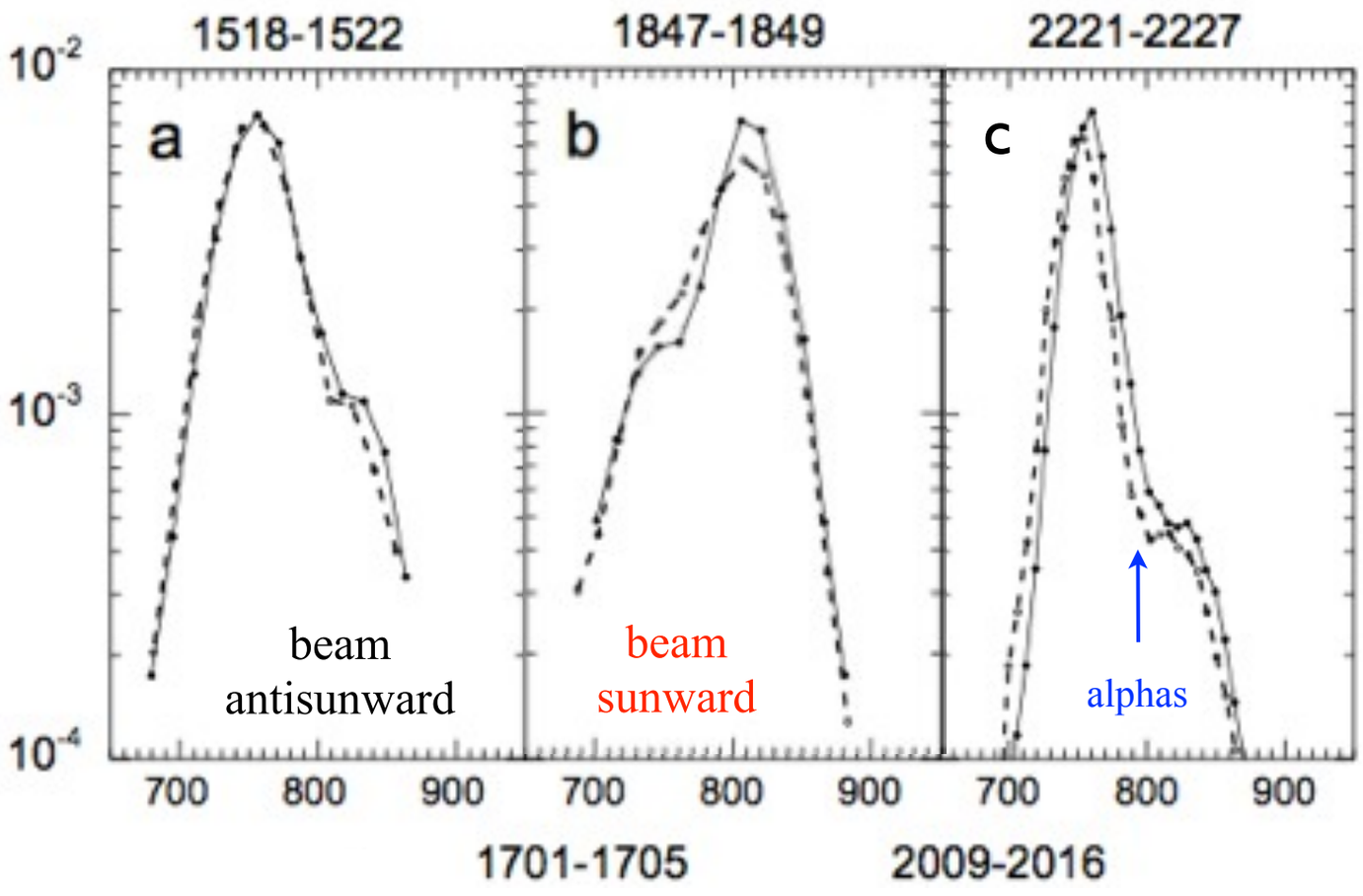
Angle between B and R

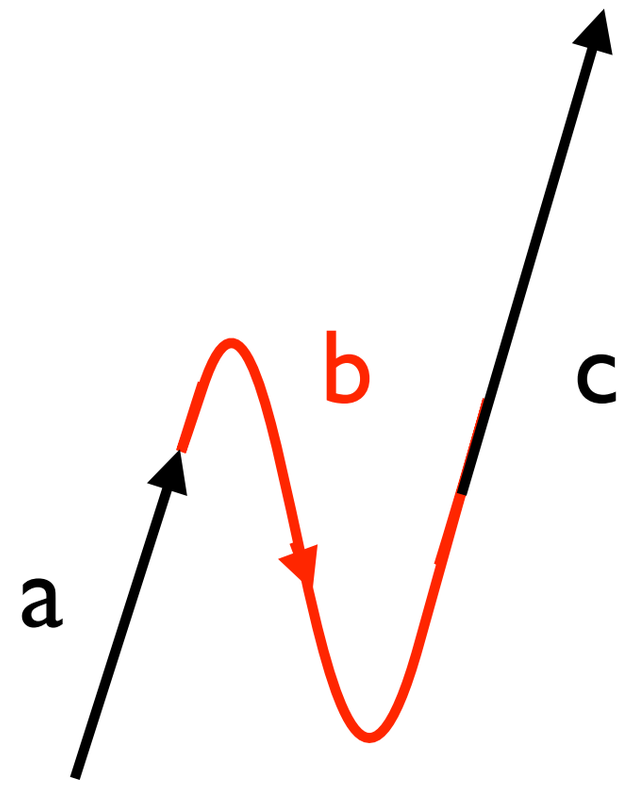


θ_{BR} oscillates around $\mathbf{B}_0$:
from 0° to 90° and beyond

Let's start from the beginning...

Magnetic field reversals (switchbacks)



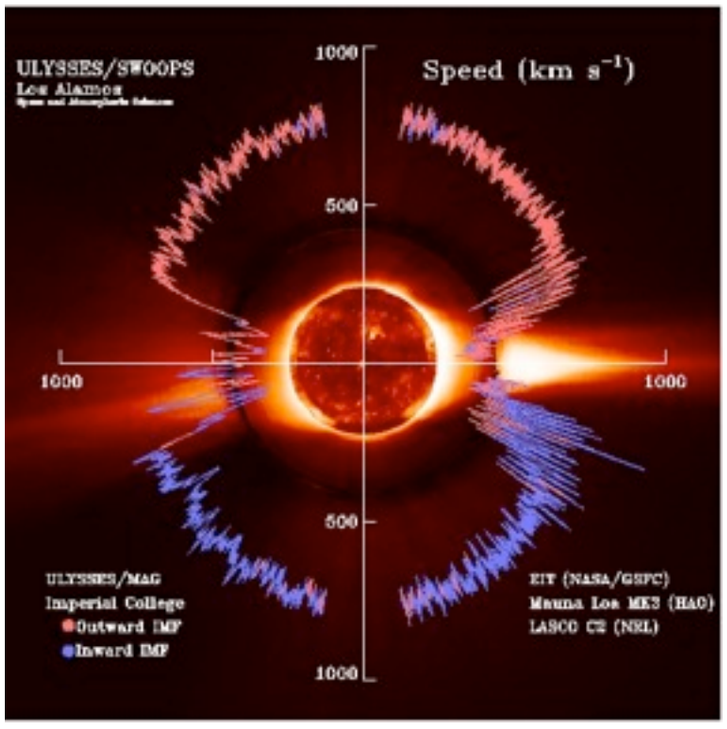


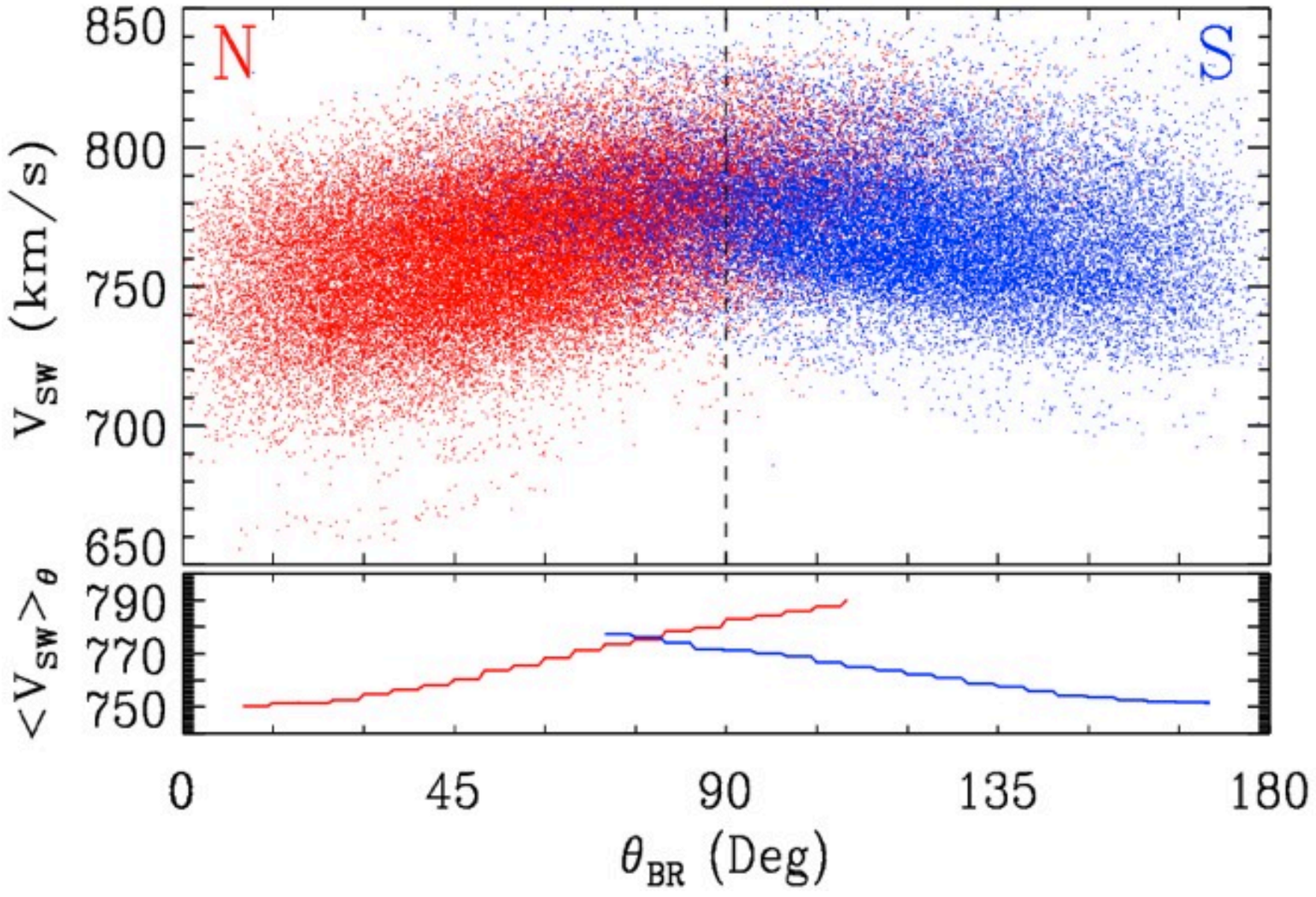
Neugebauer and Goldstein Solar Wind 13, 2013

Solar wind speed vs. θ_{BR}

(Ulysses polar passes 1994/1996)

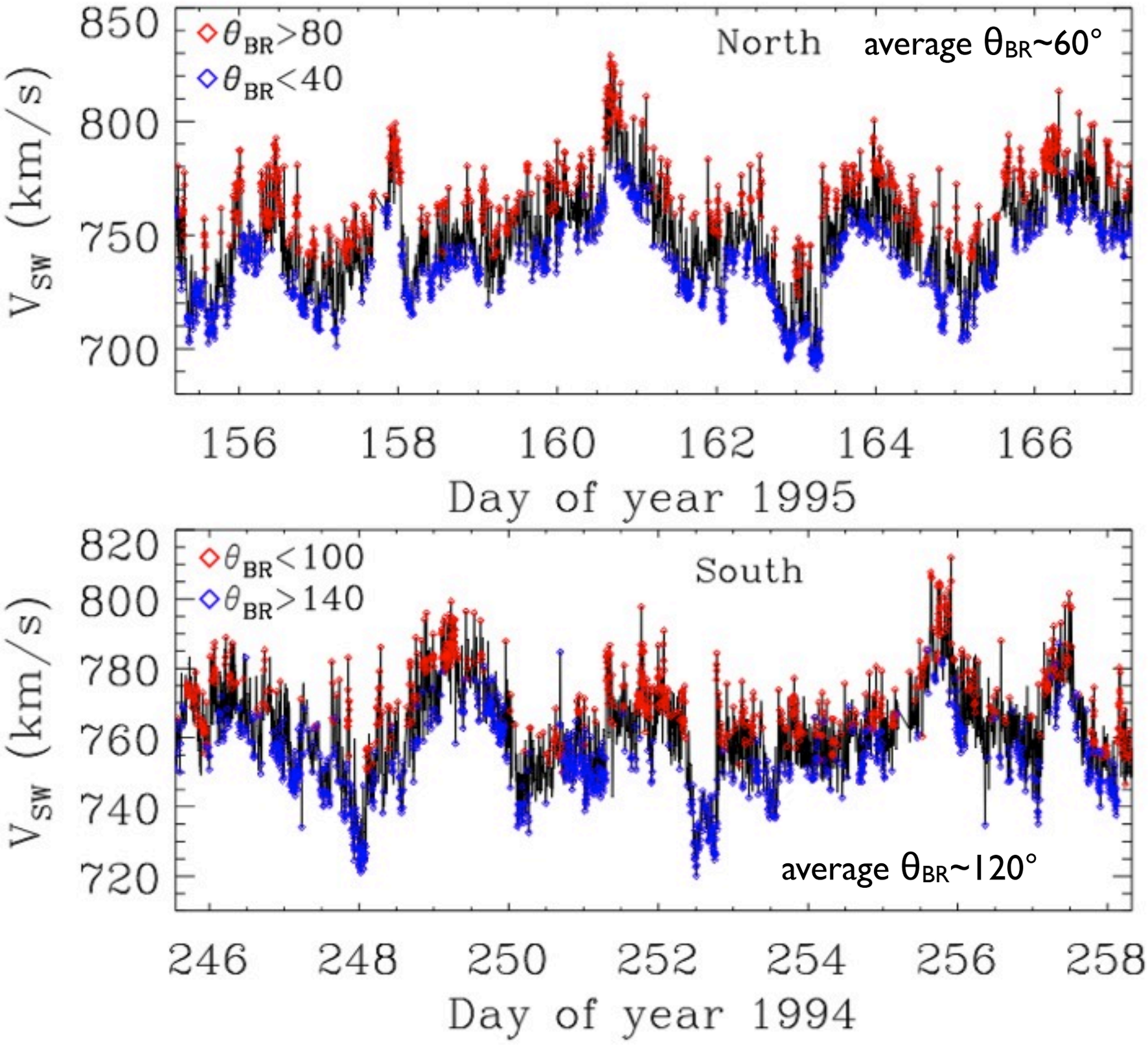
Speed is larger when θ_{BR}~90 than when the field is parallel (N) or antiparallel (S)





Matteini et al, GRL 2014

Oscillations organized by the angle θ_{BR} - 10 Days



transverse **B** = top

radial **B** = bottom

Same behavior for both magnetic field polarities

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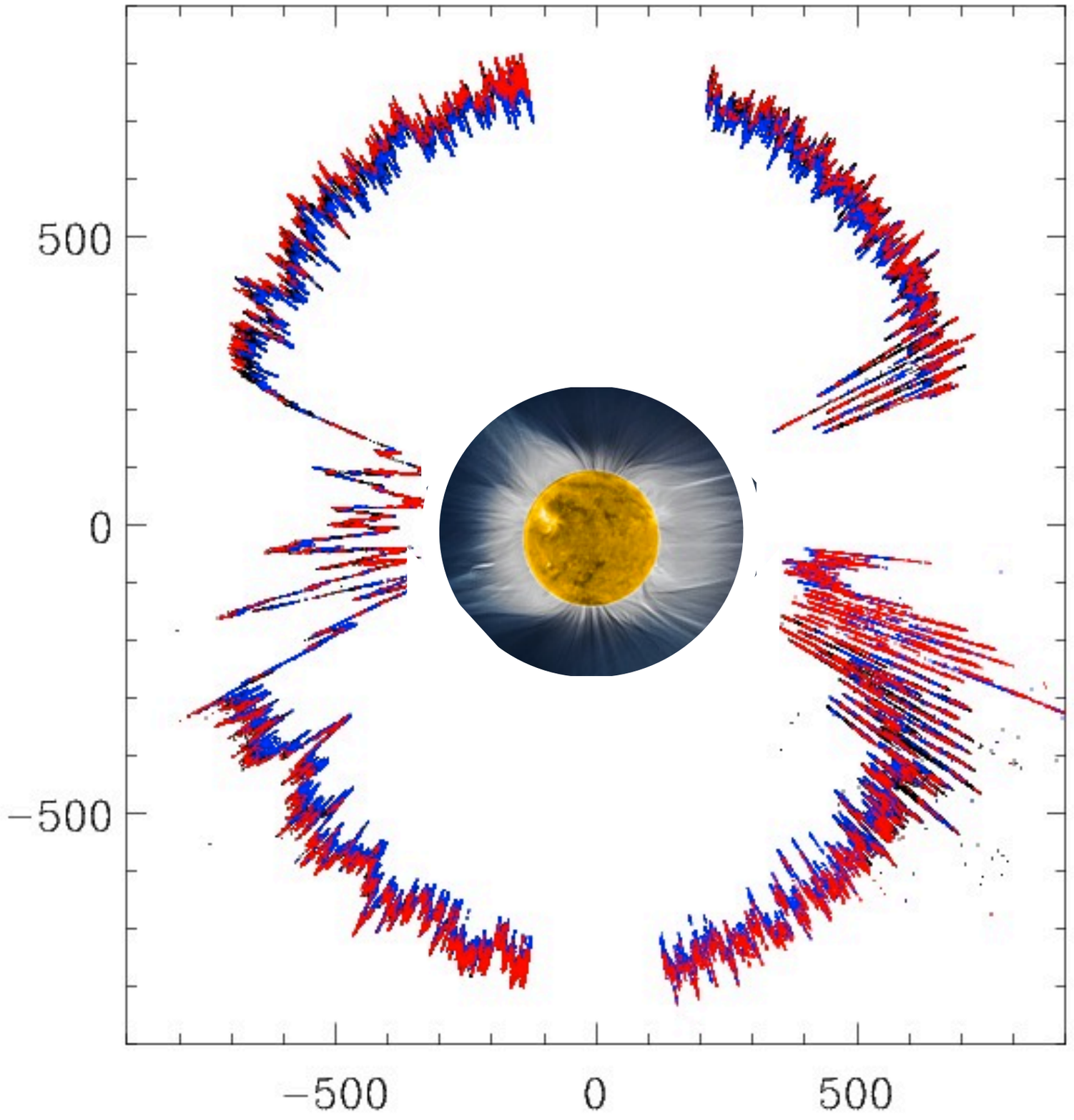

transverse **B** = top

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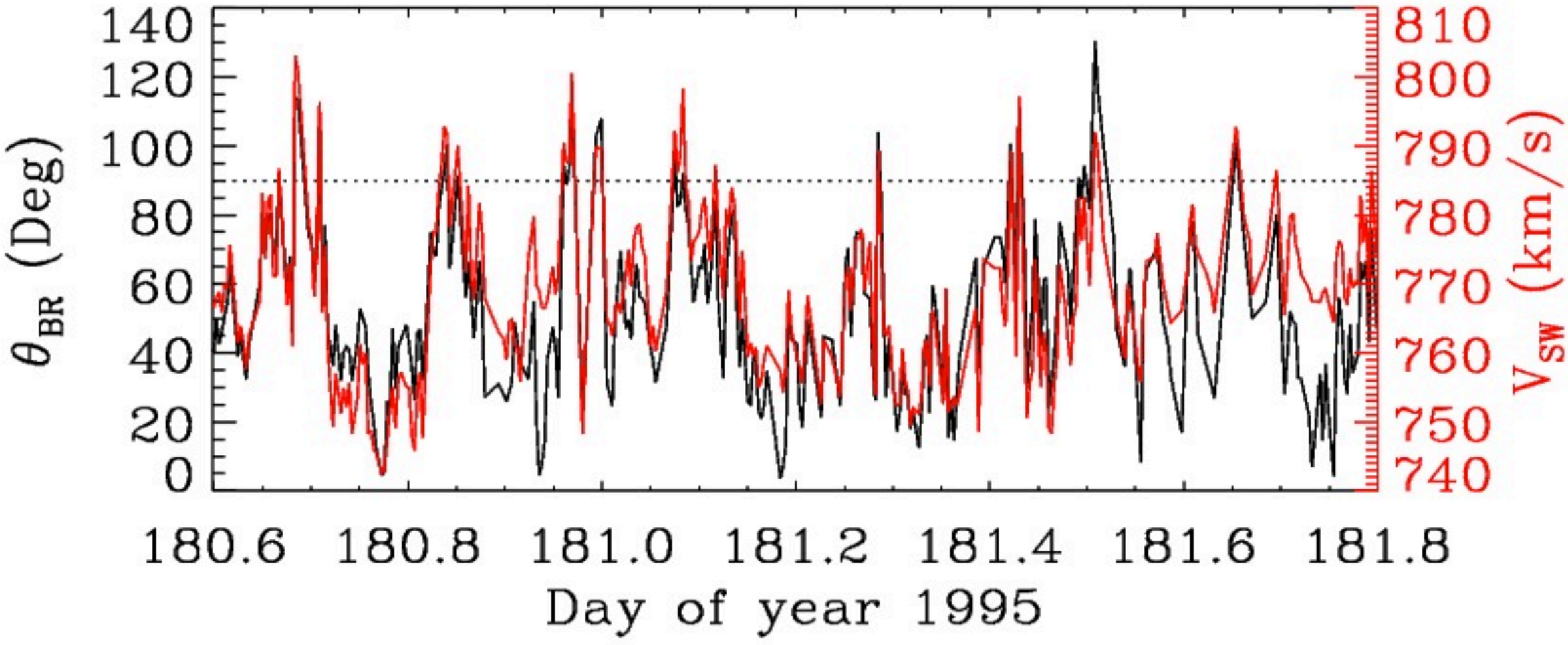
Same behavior for both magnetic field polarities

Correlation between θ_{BR} and speed - 1 Day



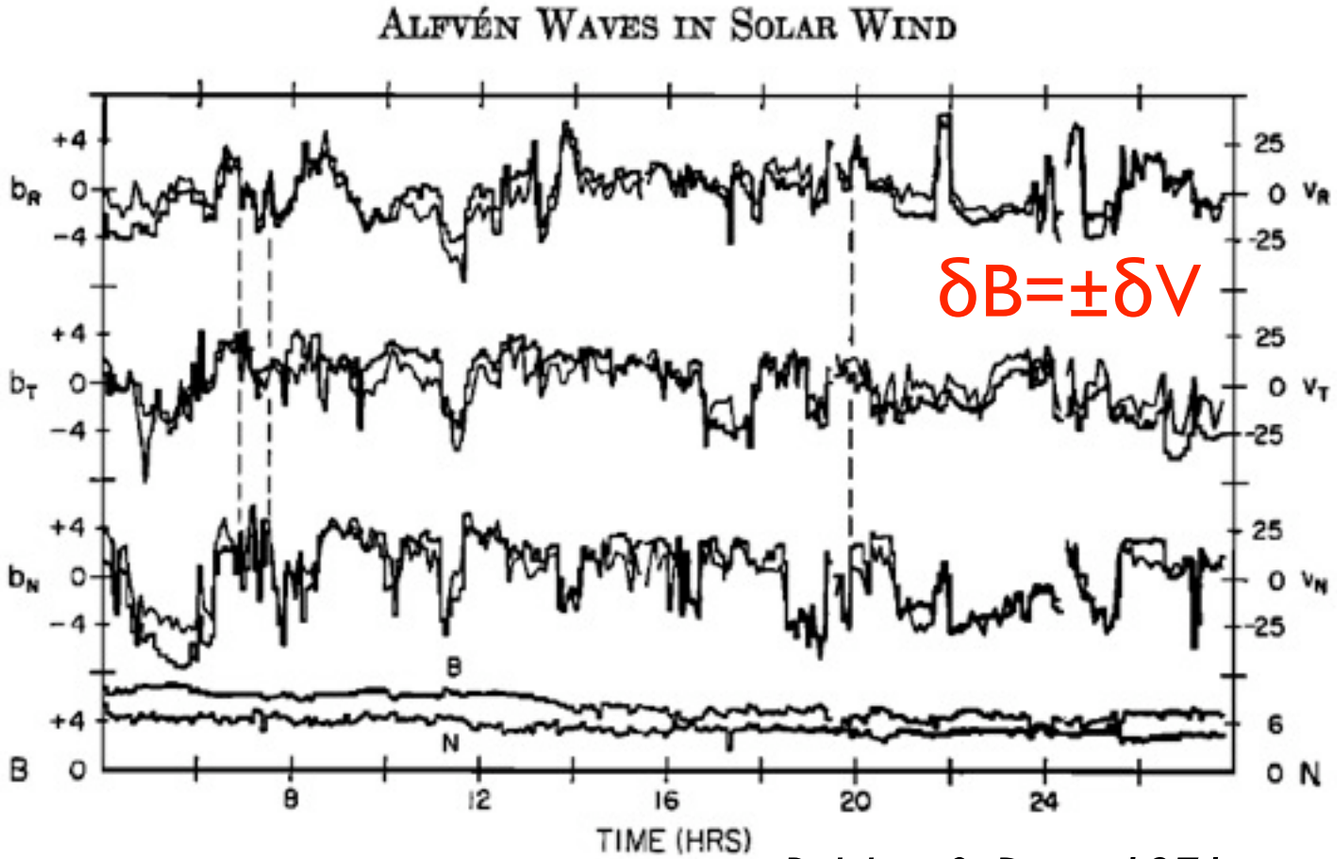
Very good correlation: same trend in θ_{BR} and V_{SW} !

Rotations of **B** beyond θ=90° correspond to peaks in speed

Alfvénic fluctuations in the solar wind

Strong correlation between magnetic and velocity fluctuations

polarization of anti-sunward propagating Alfvén waves



Belcher & Davis 1971

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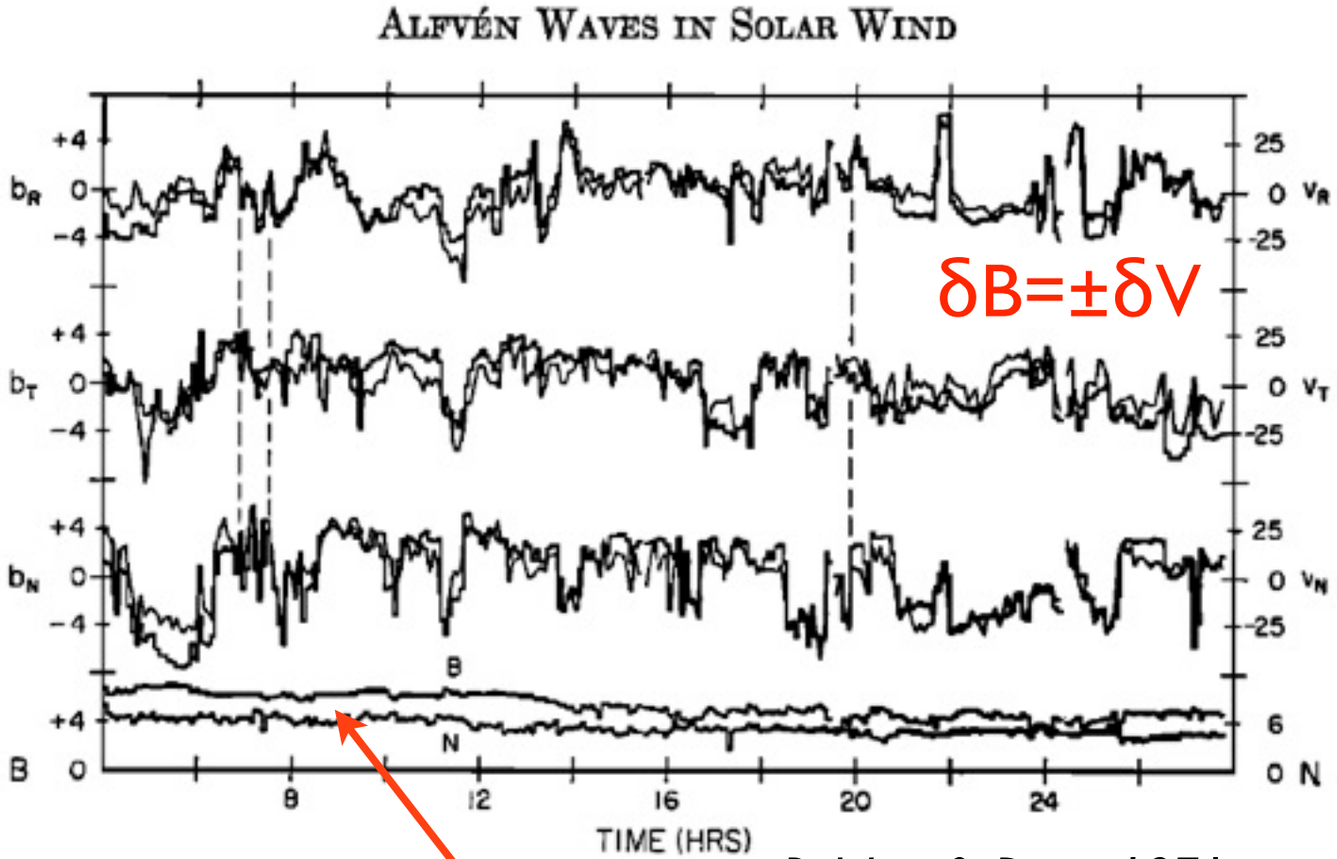

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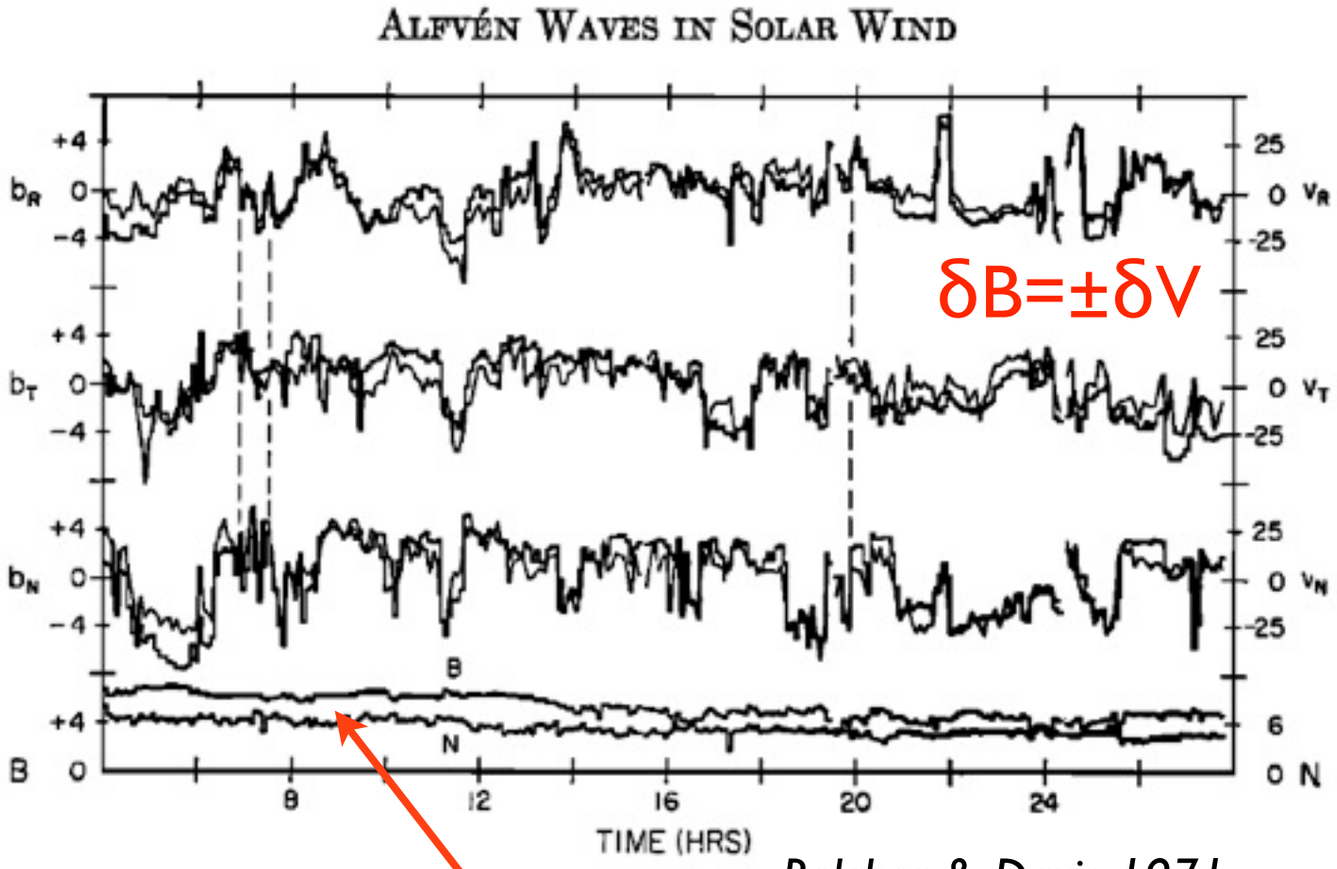
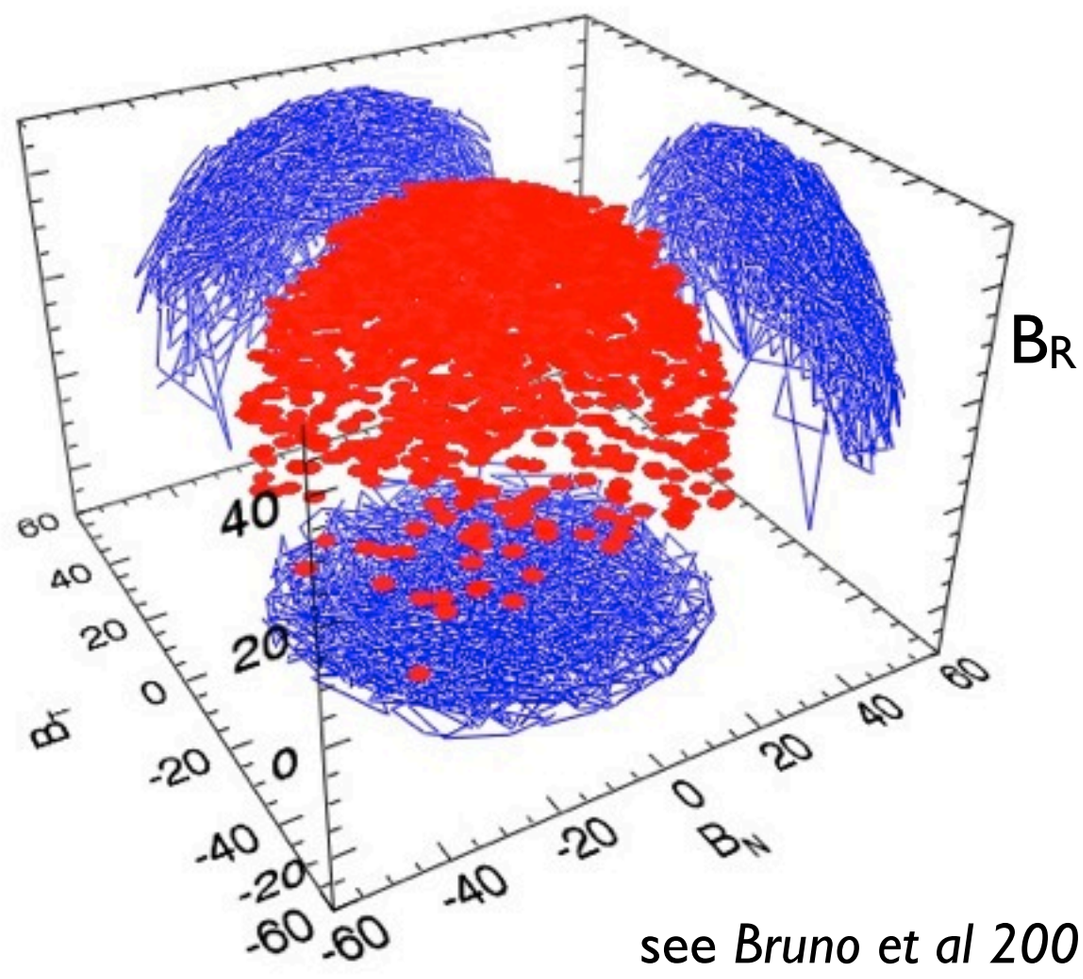


Belcher & Davis 1971

|B|~const

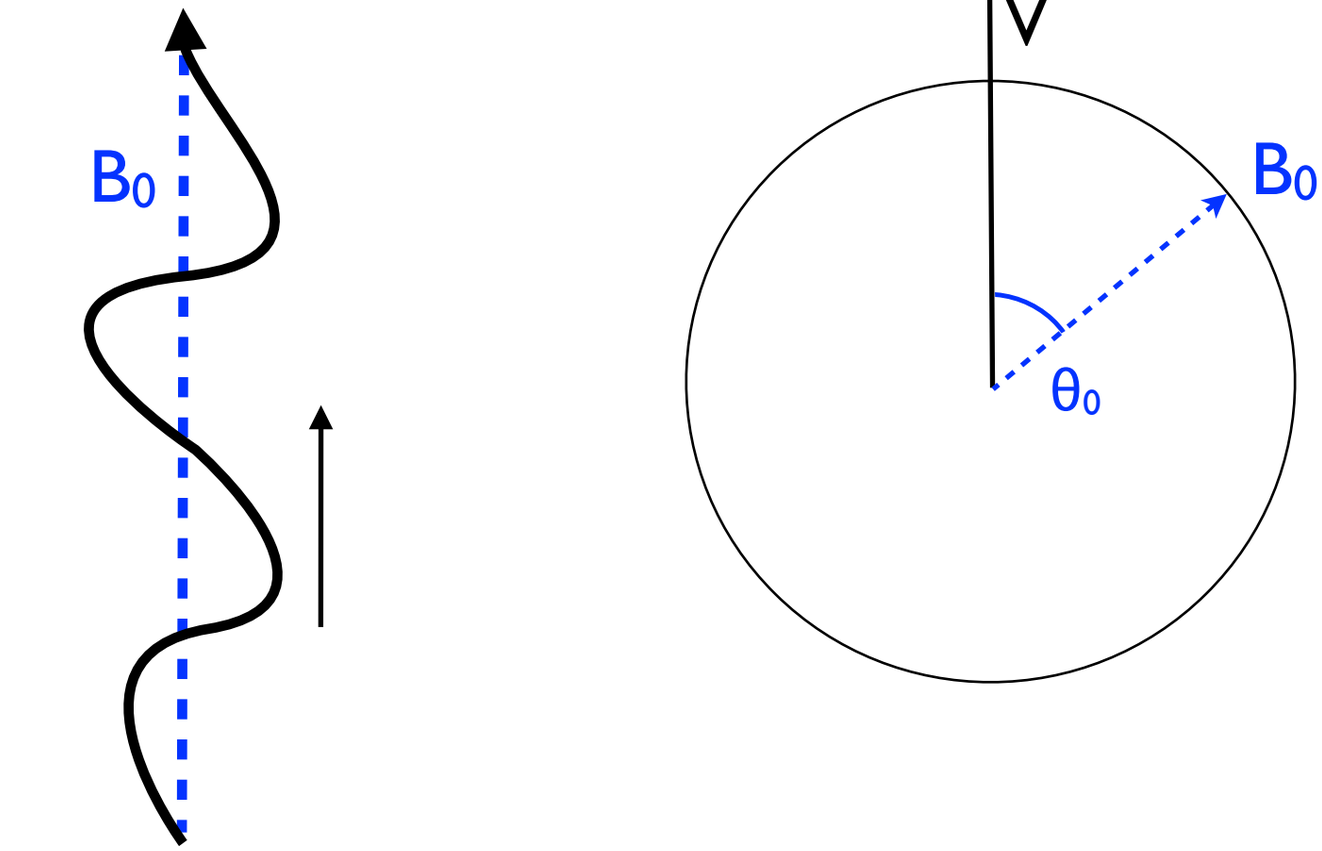
Tip of magnetic field vector moves on a sphere



see *Bruno et al 2001*

A simple model of Alfvénic fluctuations

|**B**|=constant



Alfvén waves

Sun

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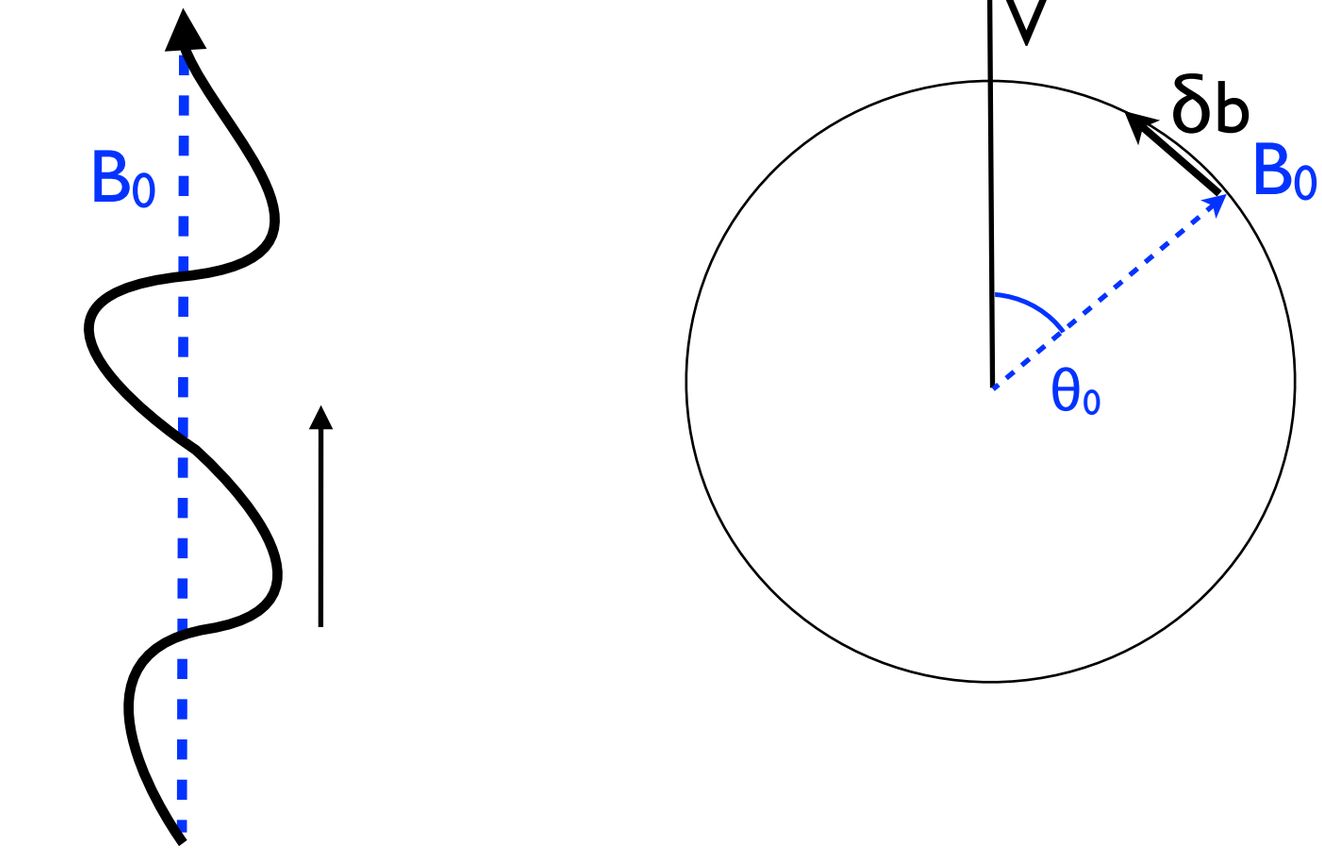

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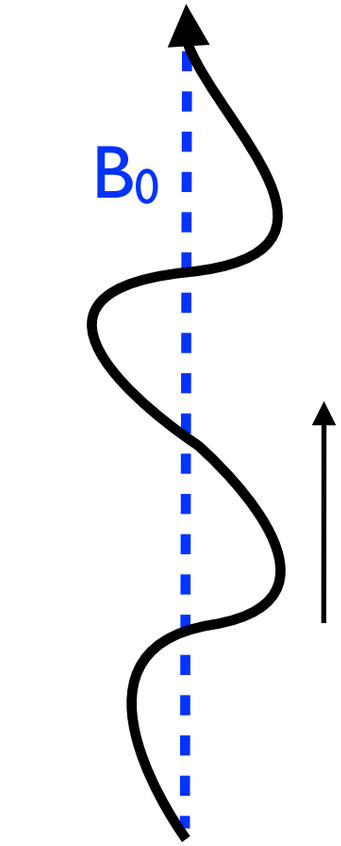

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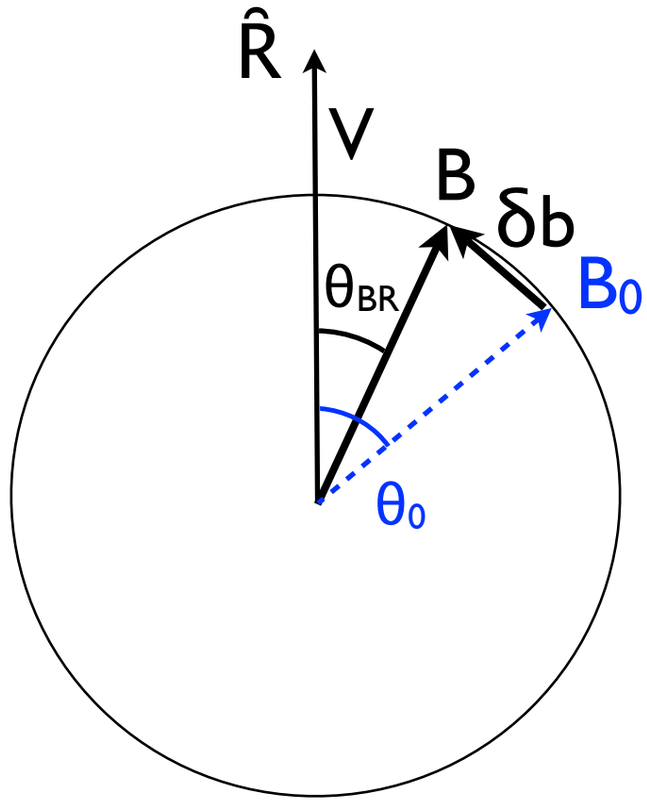

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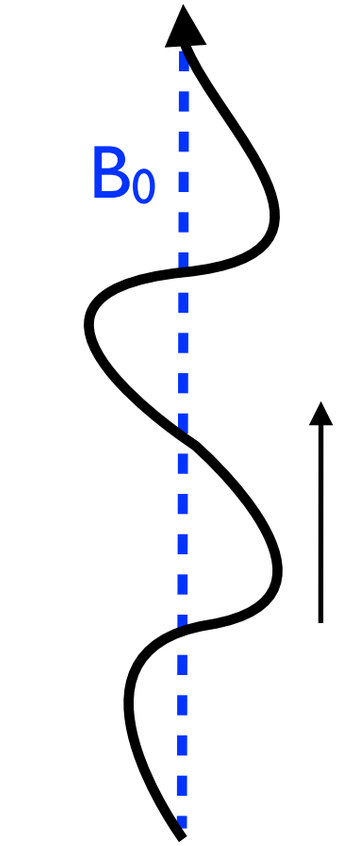

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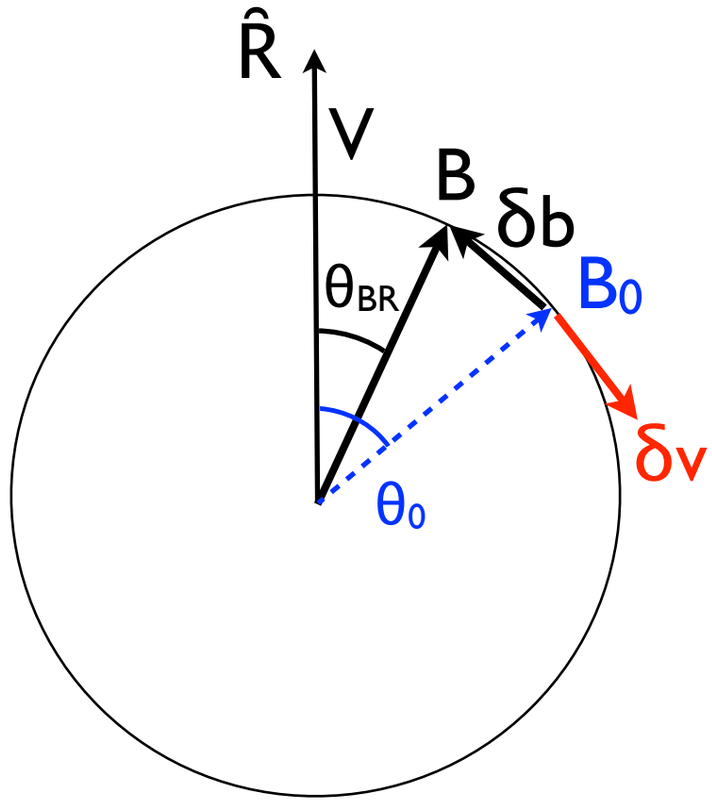

Sun

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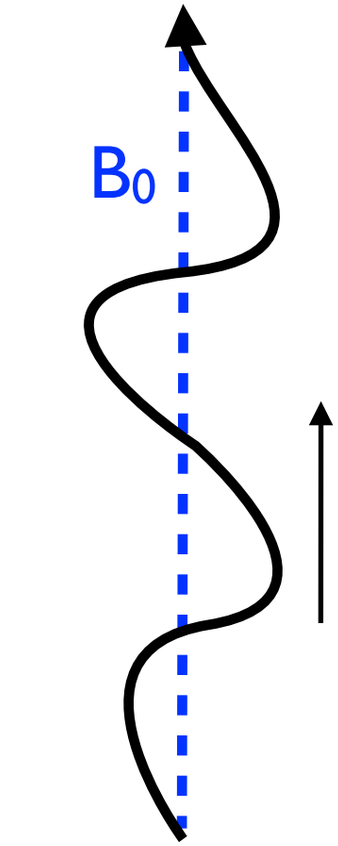

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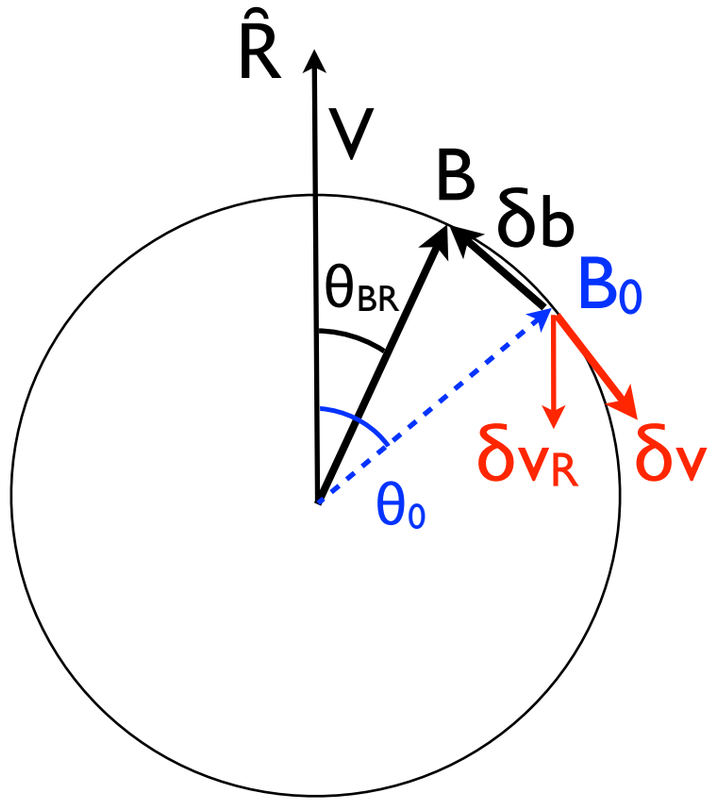

Sun

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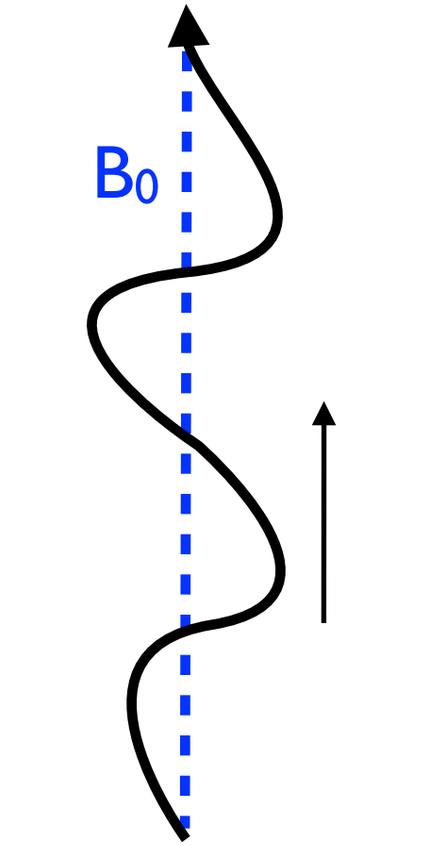

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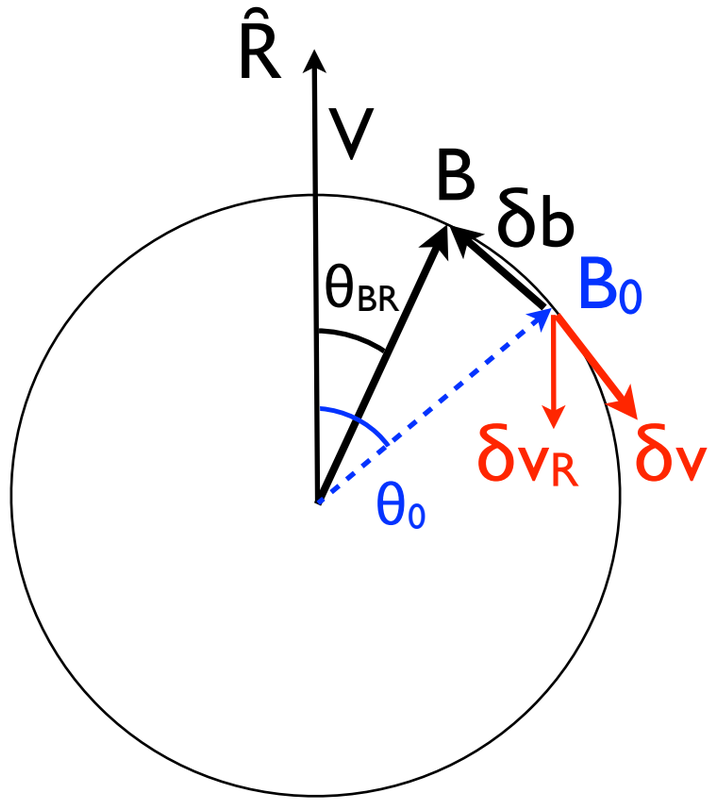

Sun

speed decreses

A simple model of Alfvénic fluctuations

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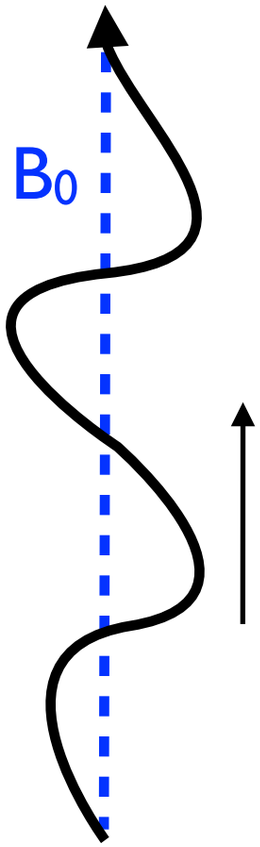

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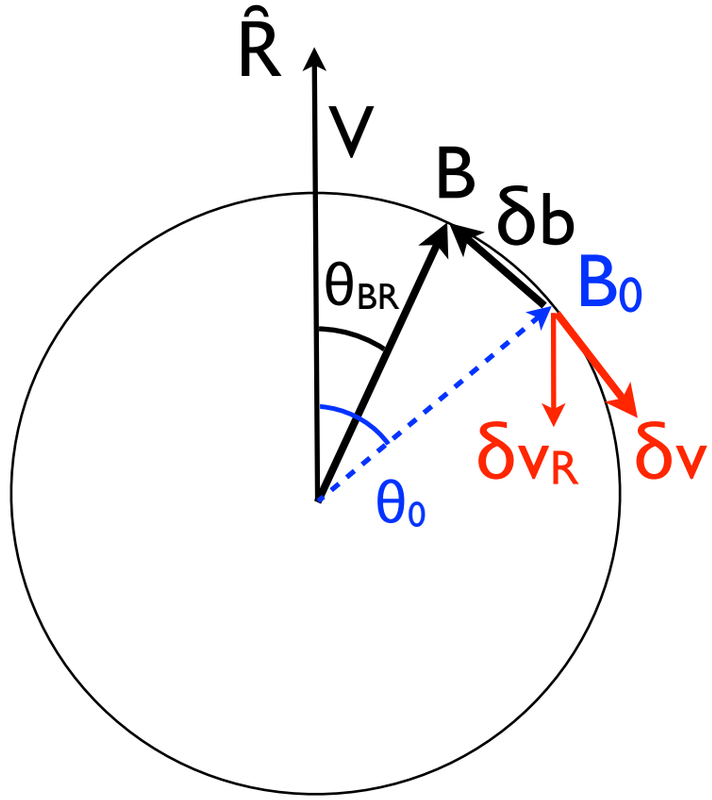

Sun

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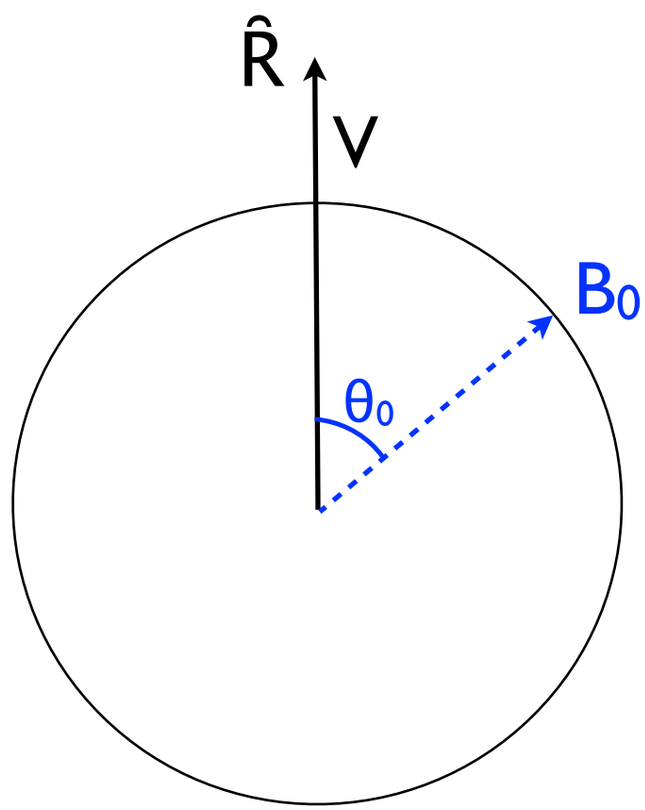

Sun

A simple model of Alfvénic fluctuations

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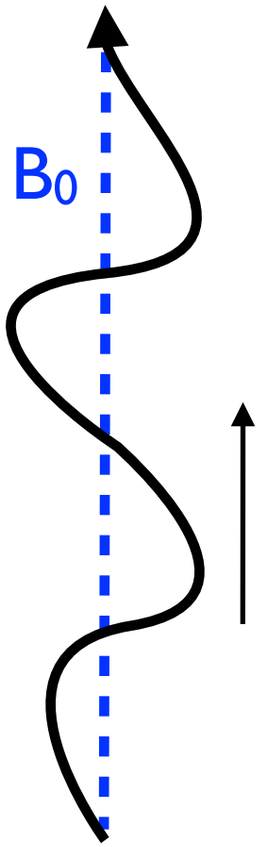

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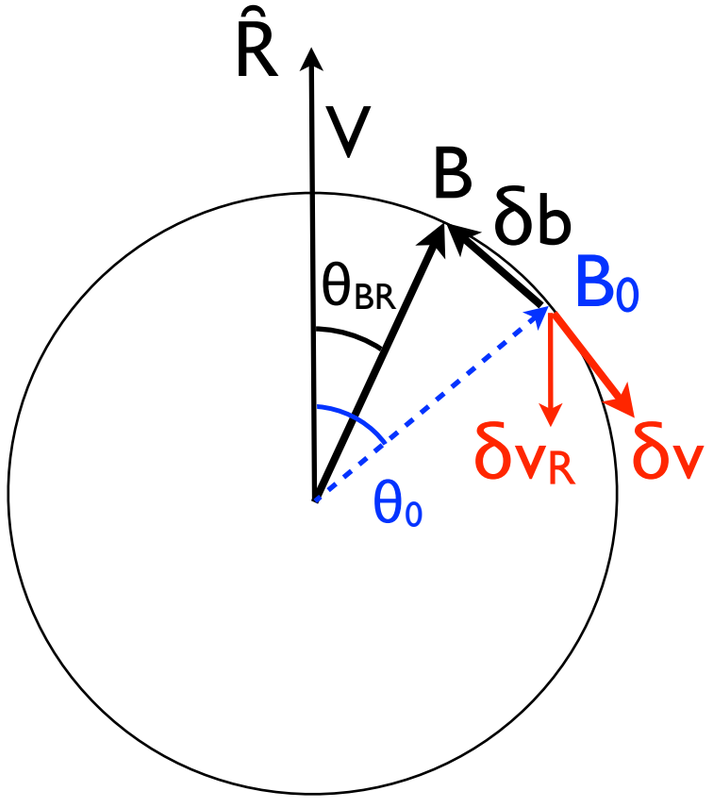

Sun

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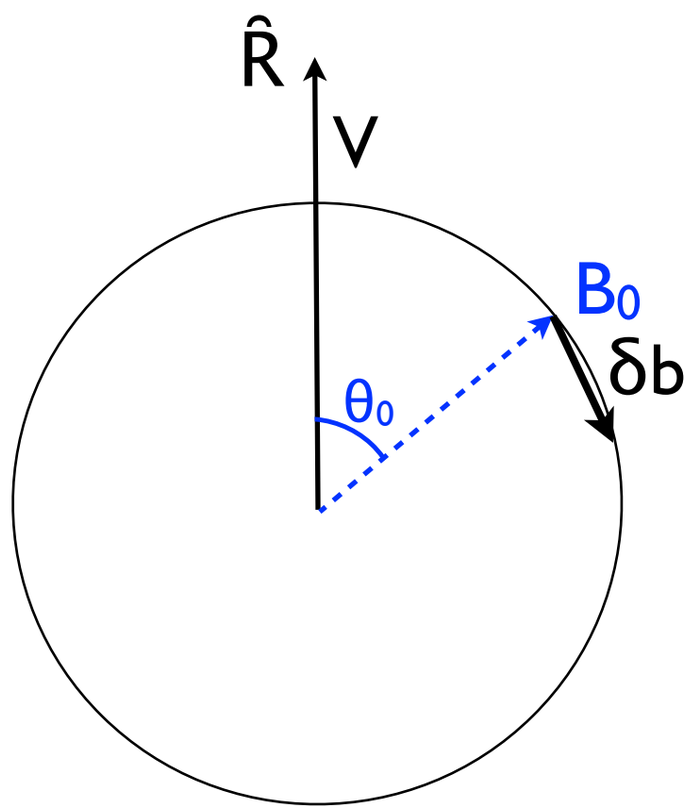

Sun

A simple model of Alfvénic fluctuations

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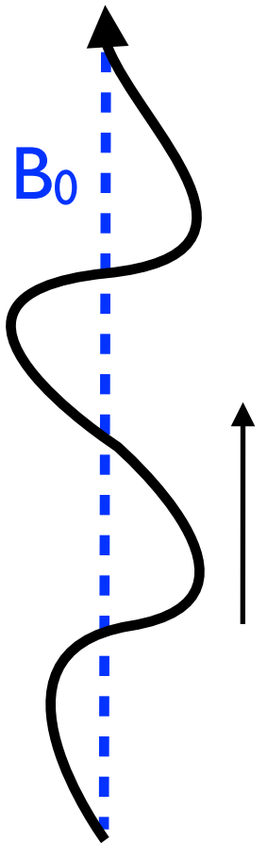

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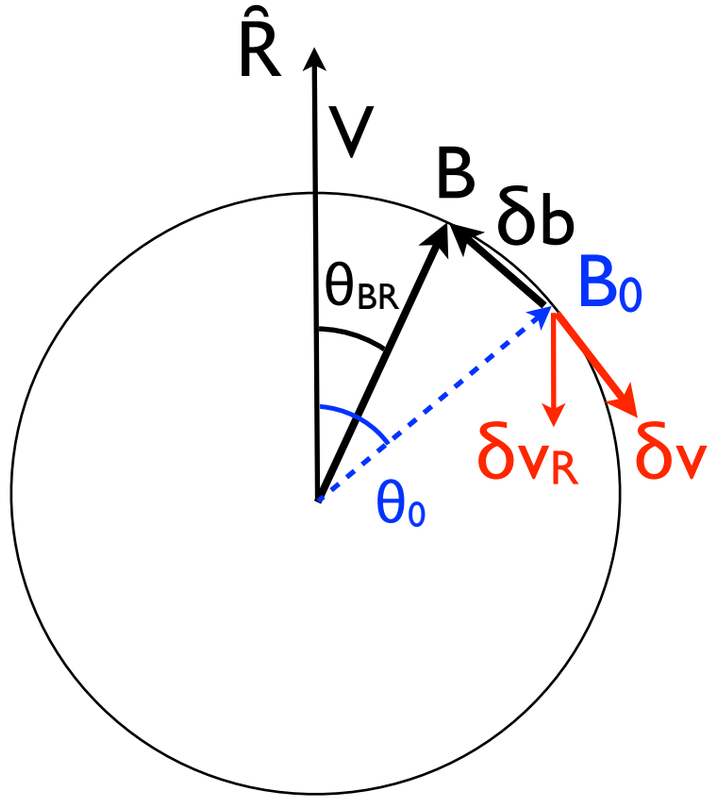

Sun

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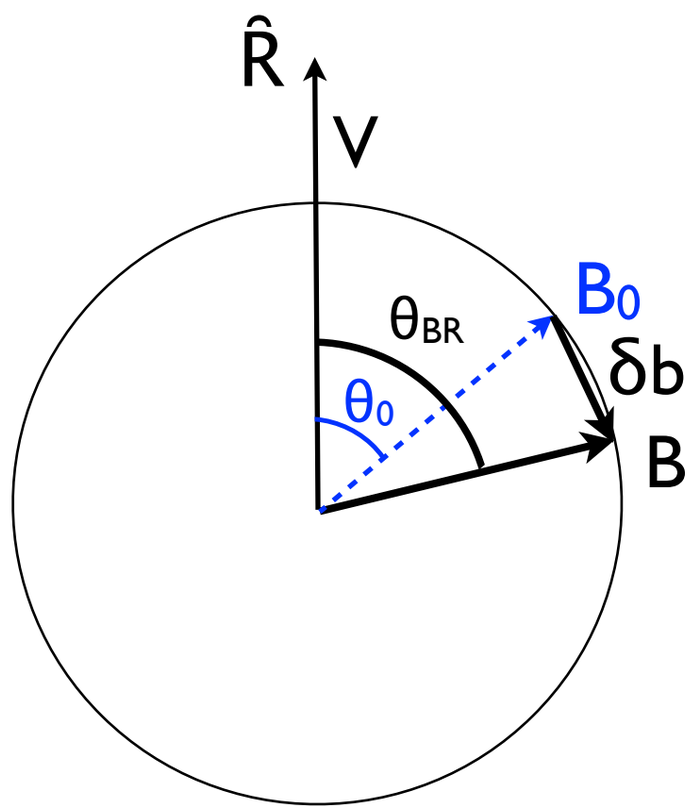

Sun

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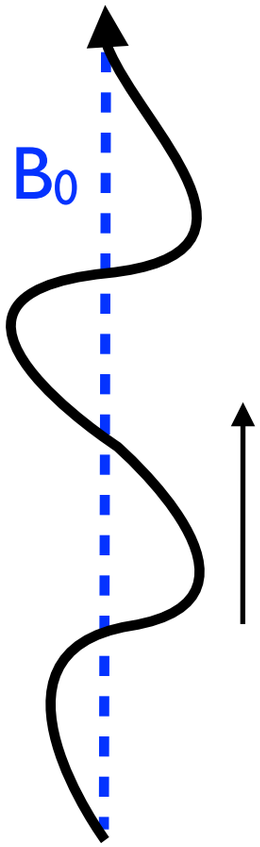

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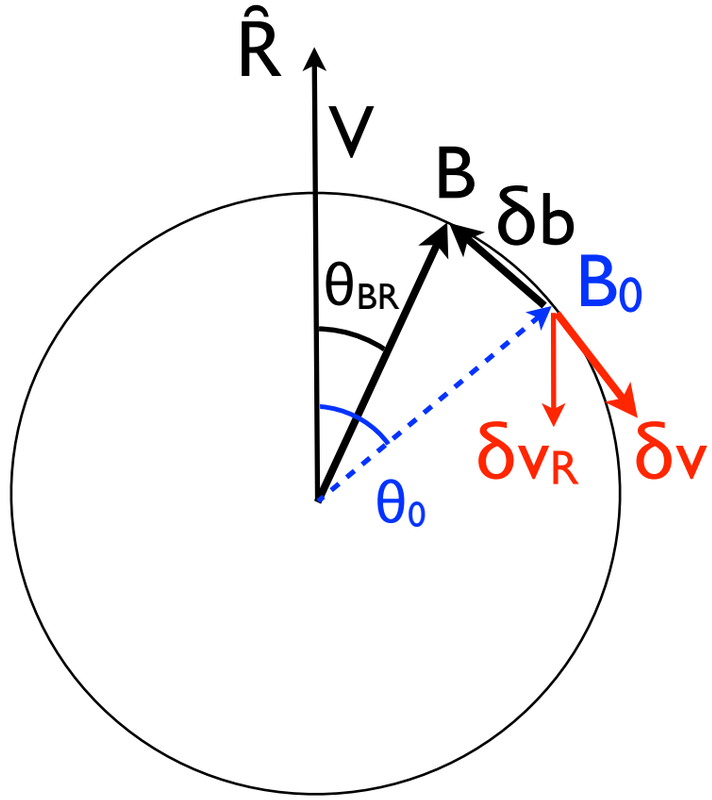

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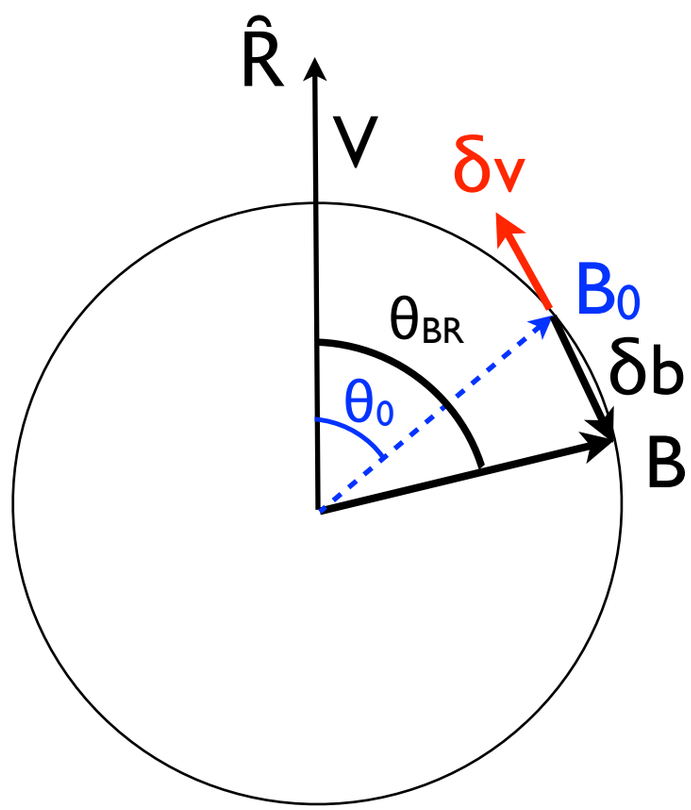

Sun

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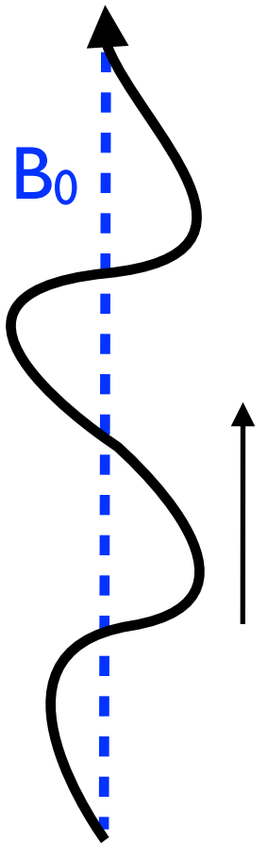

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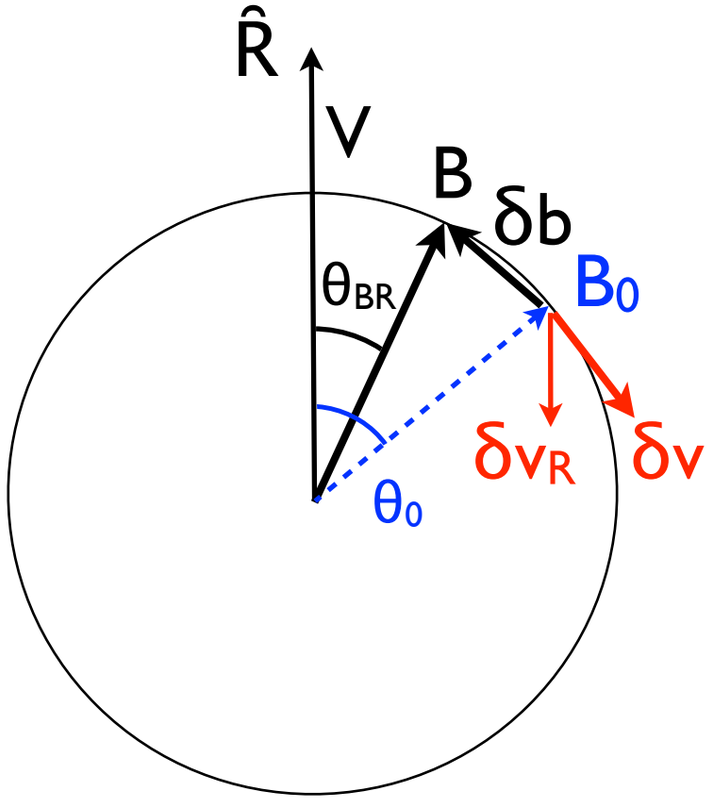

Sun

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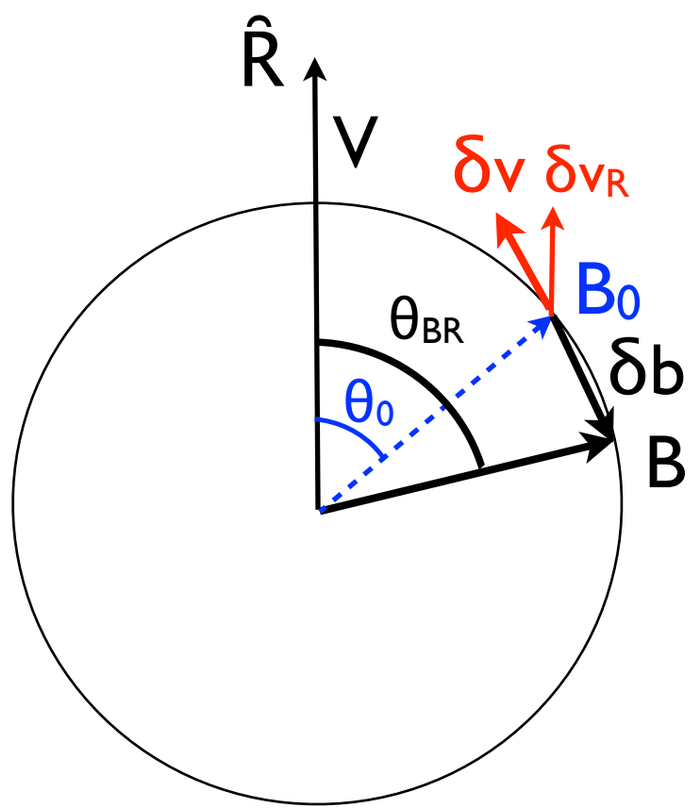

Sun

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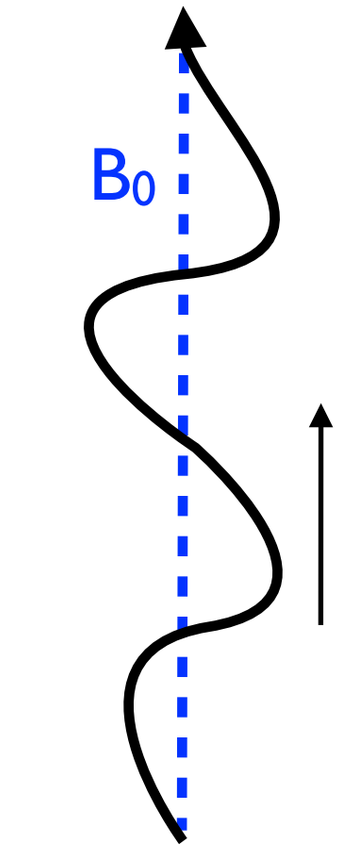

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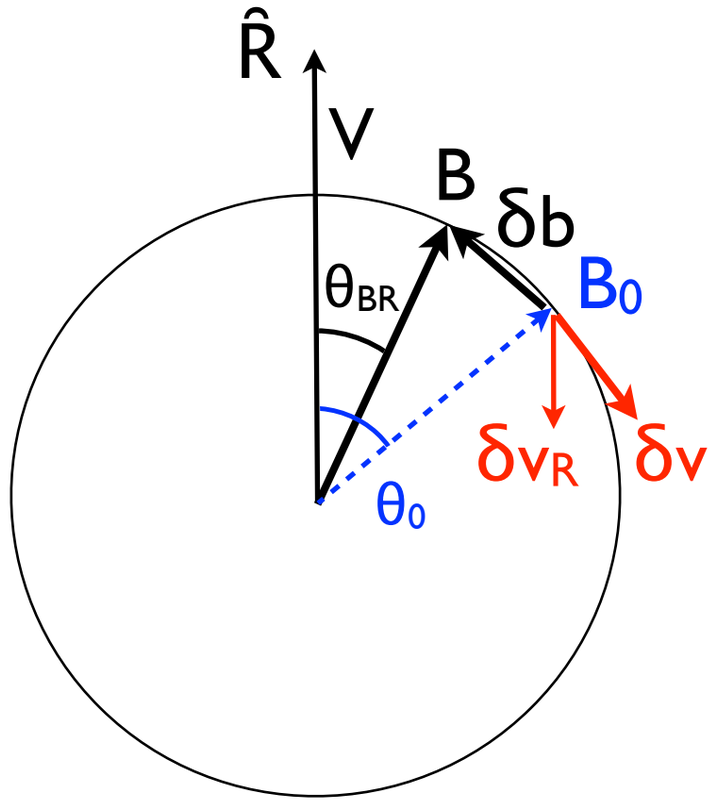

Sun

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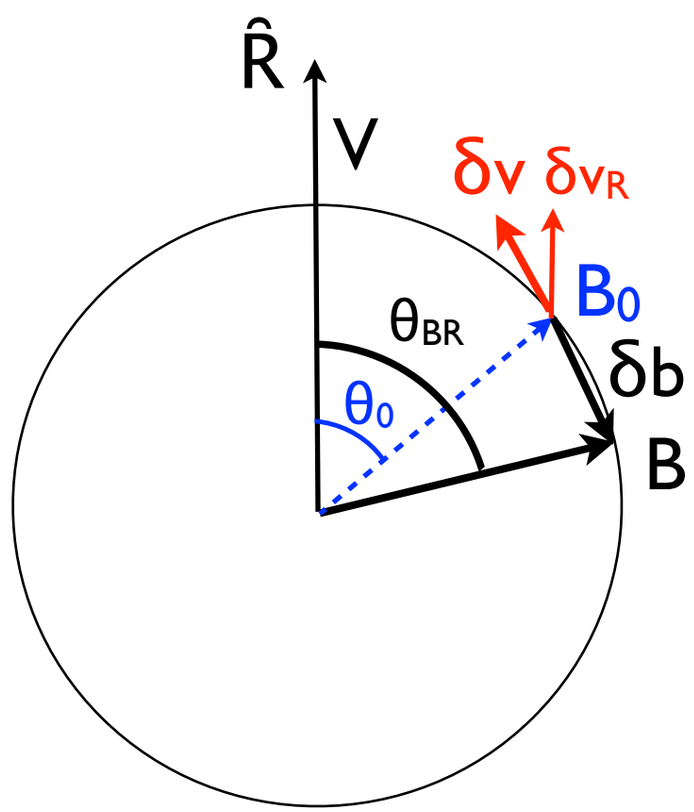

Sun

speed increases

A simple model of Alfvénic fluctuations

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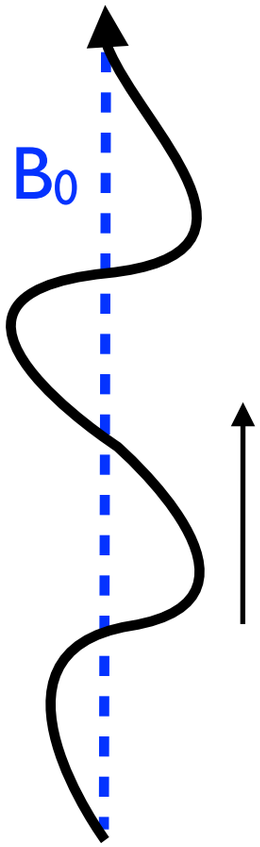

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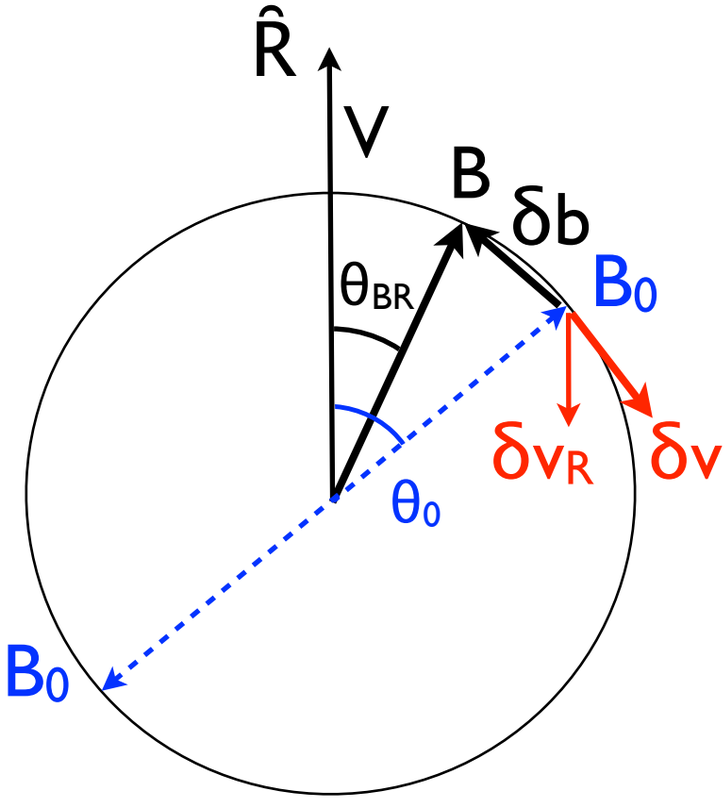
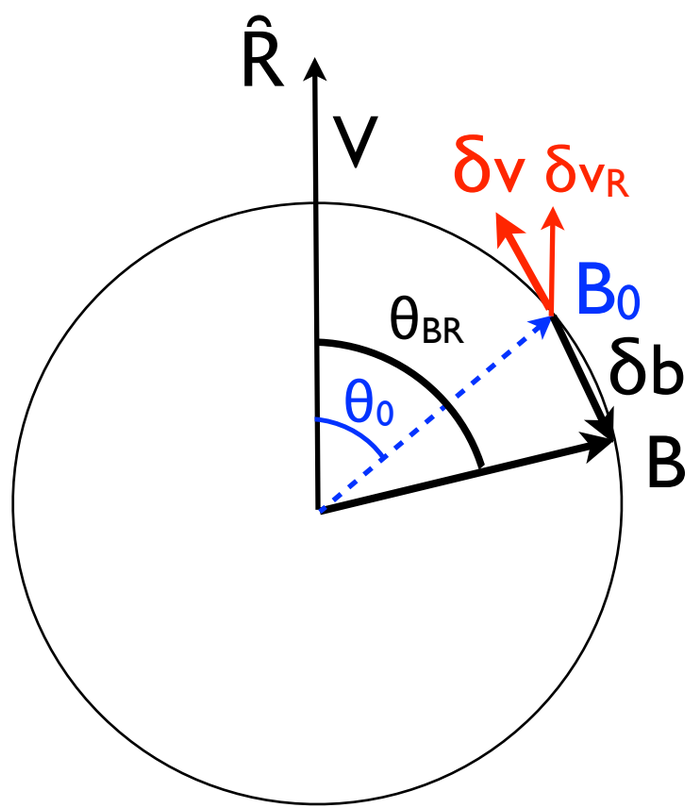


Sun

speed decreses



Sun

speed increases

A simple model of Alfvénic fluctuations

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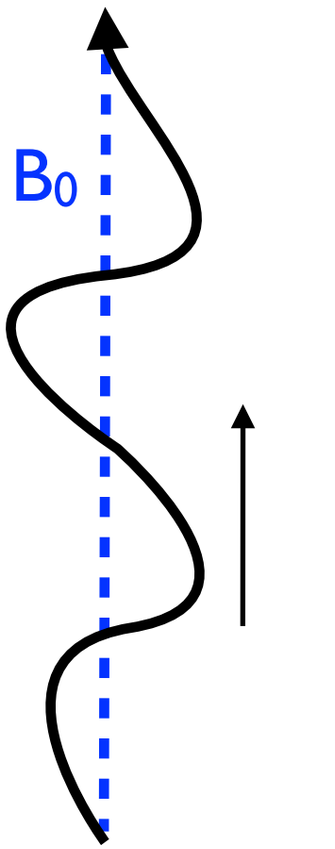

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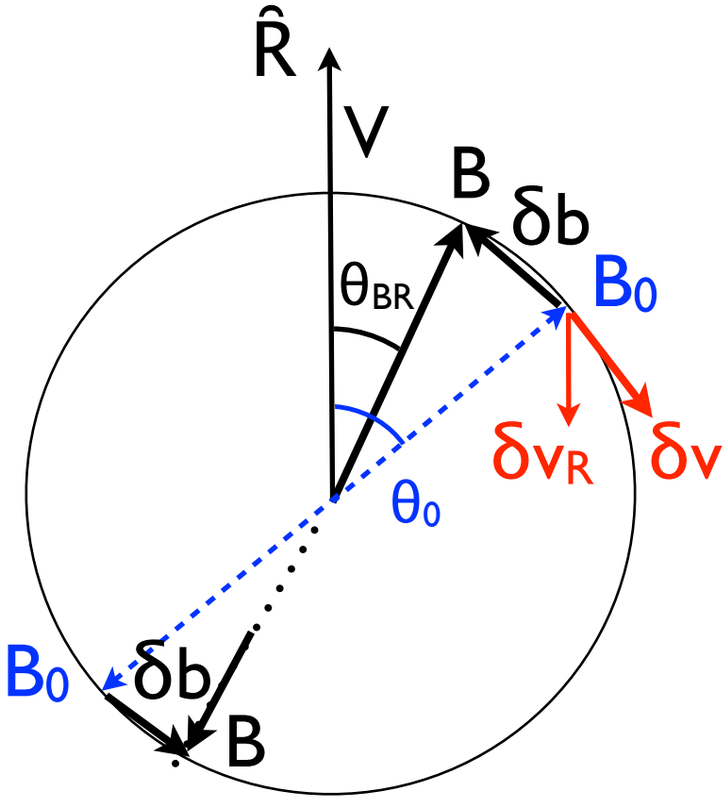
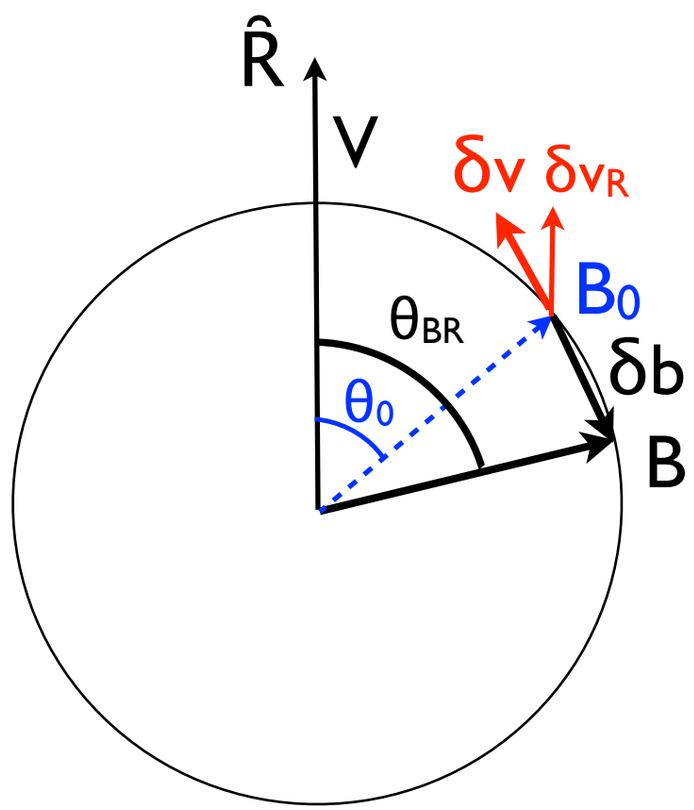


Sun

speed decreses



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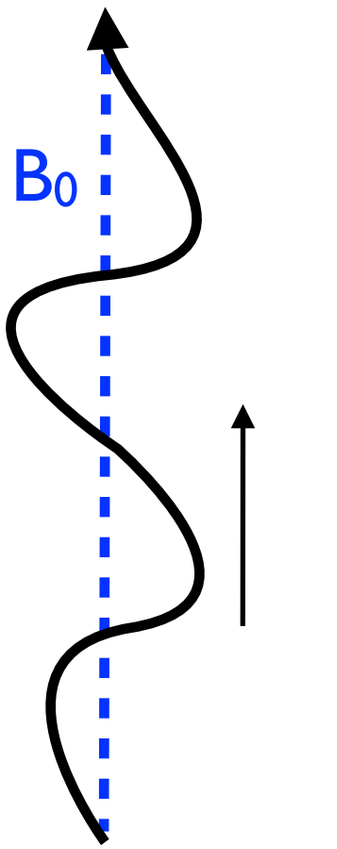
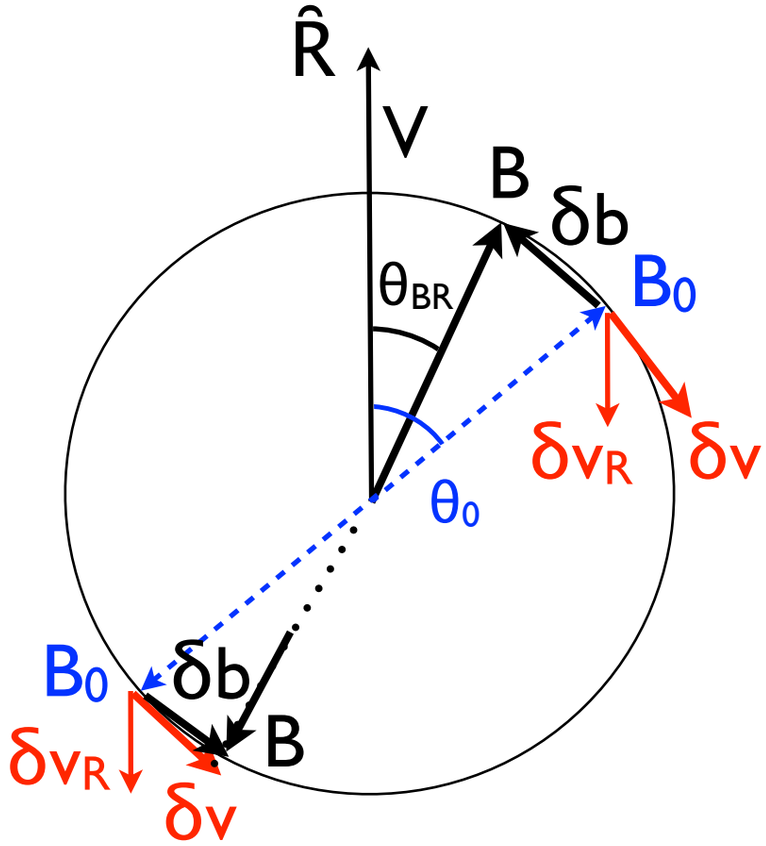
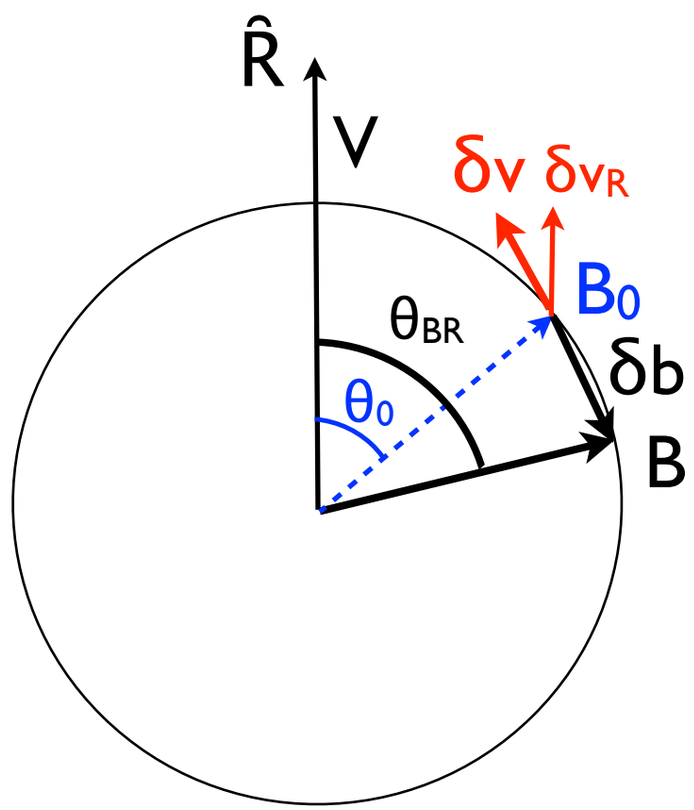


Alfvén waves



Sun

speed decreses



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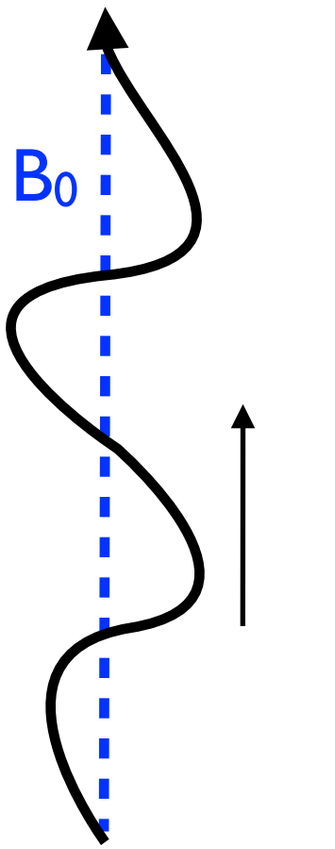

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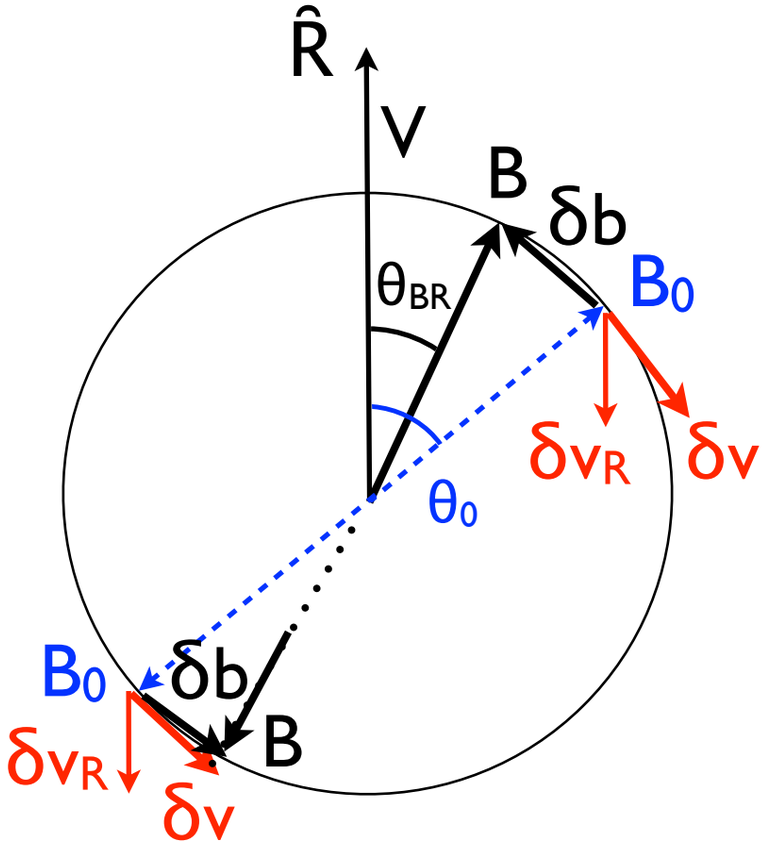
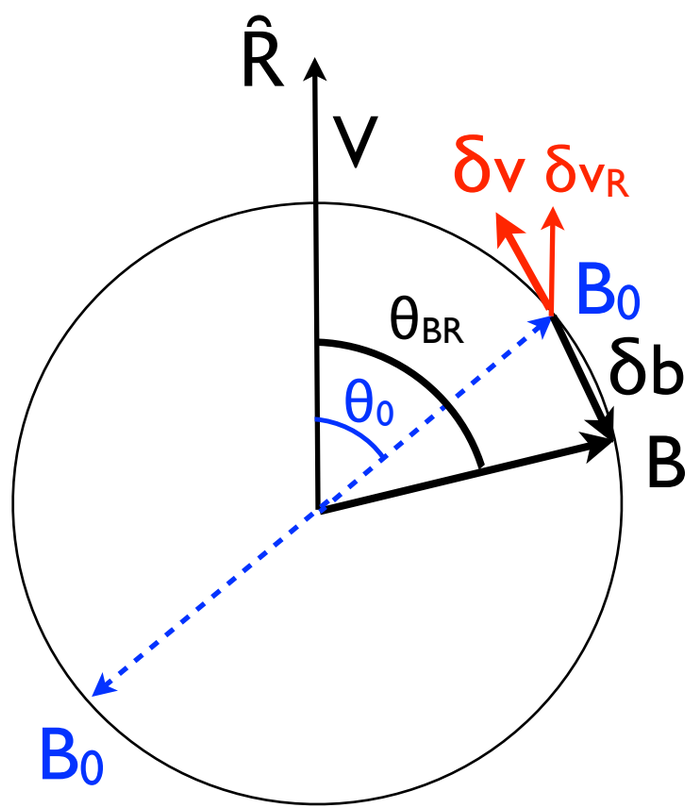


Sun

speed decreses

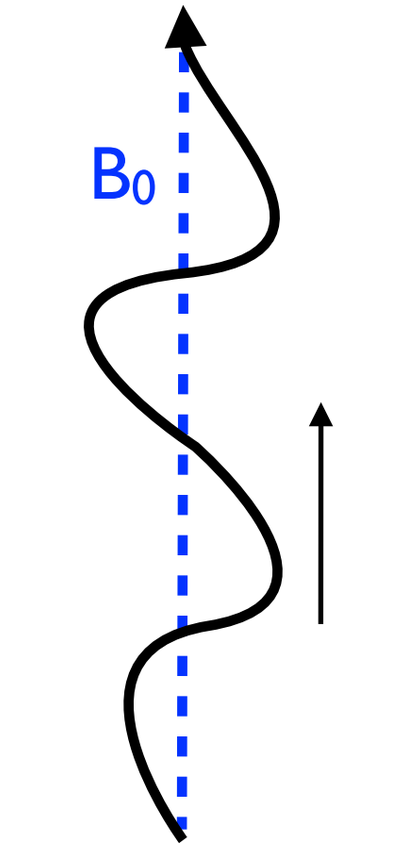


Sun

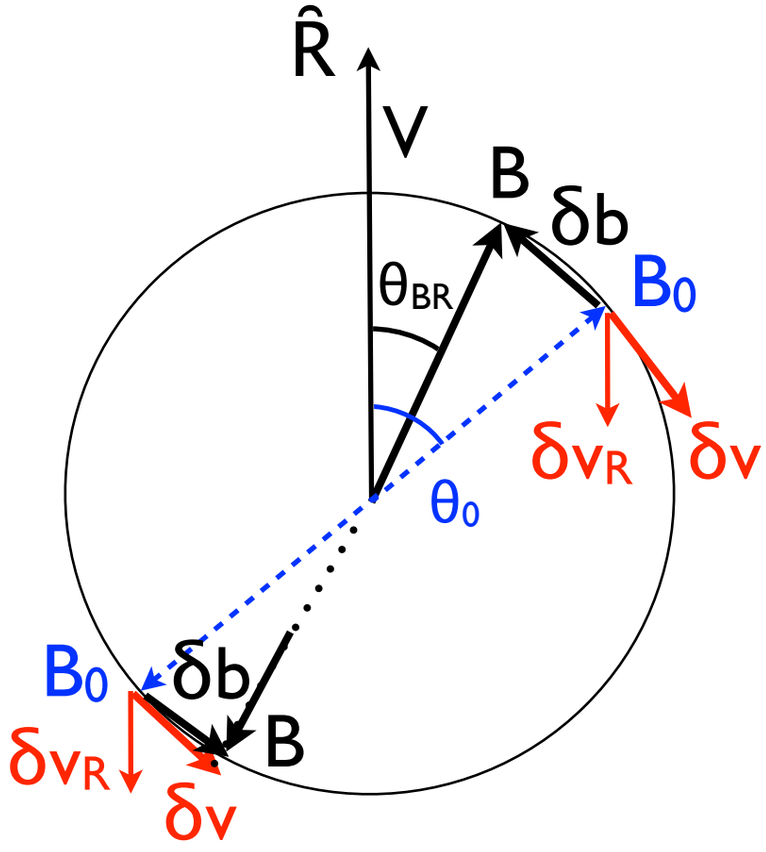
speed increases

A simple model of Alfvénic fluctuations

|**B**|=constant

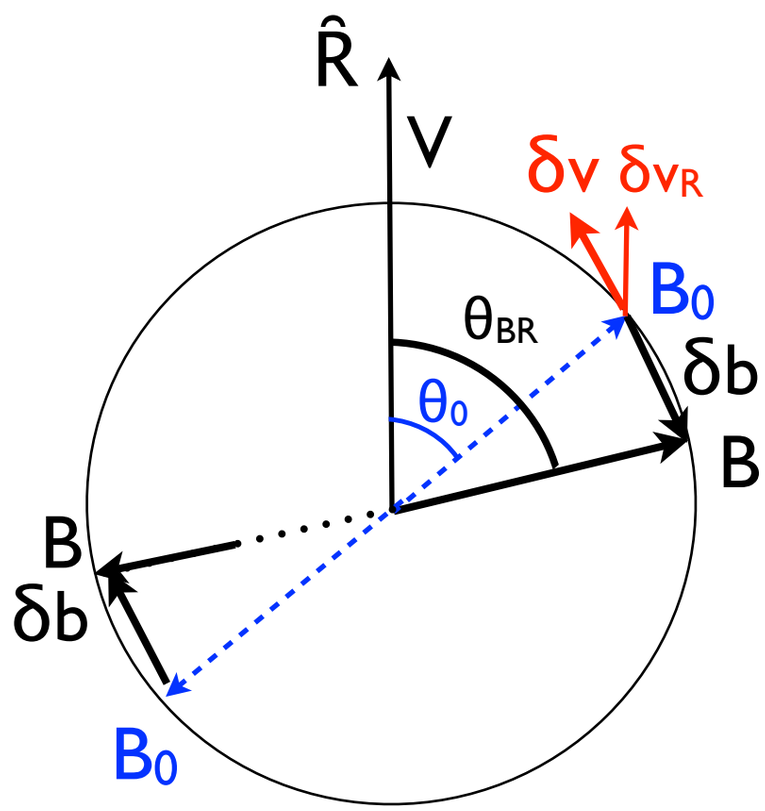


Alfvén waves



Sun

speed decreses

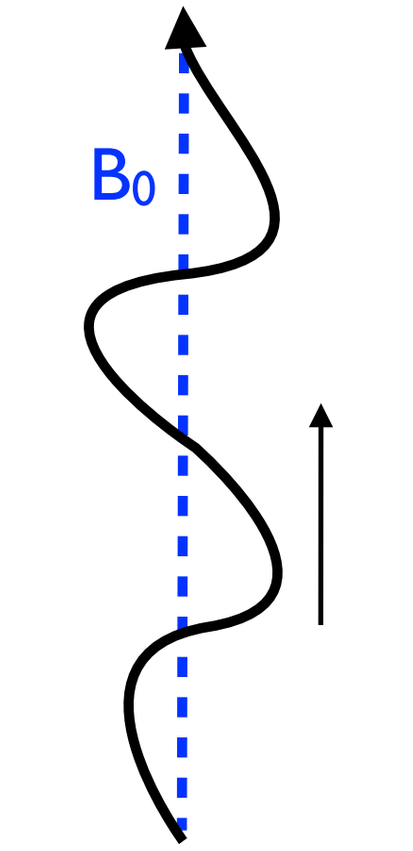


Sun

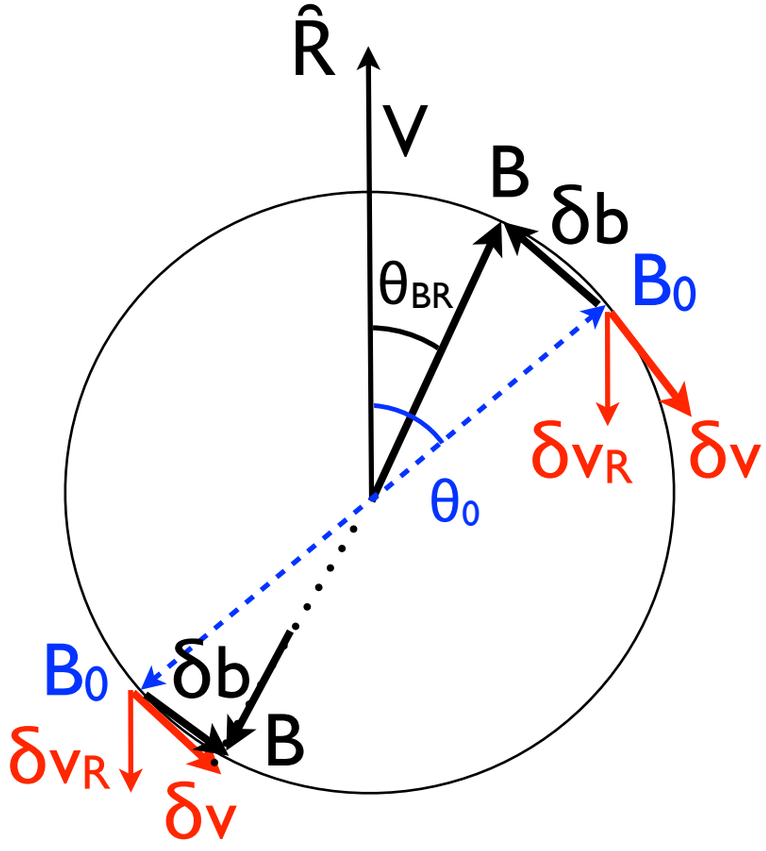
speed increases

A simple model of Alfvénic fluctuations

|**B**|=constant

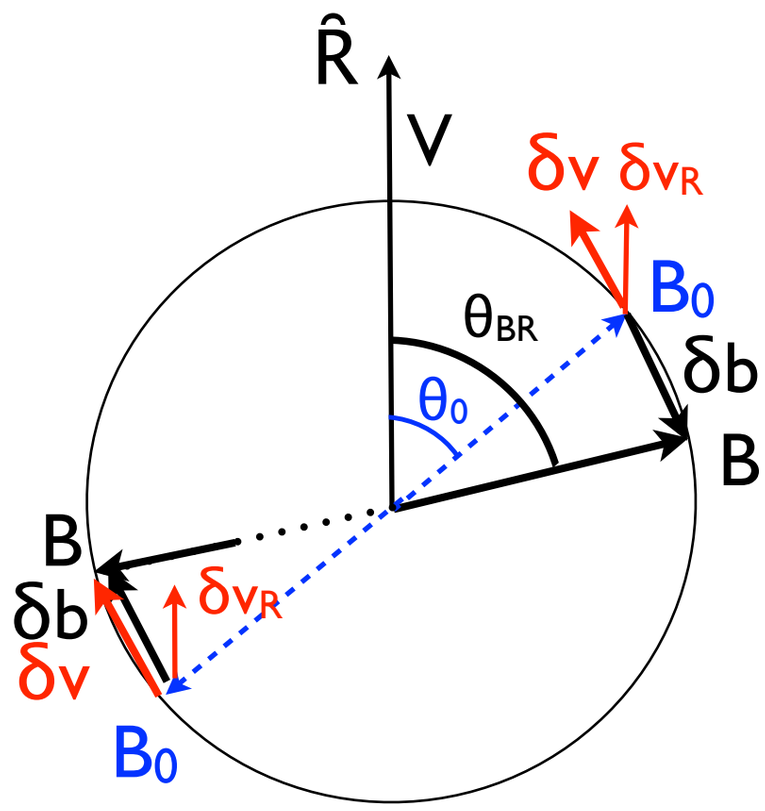


Alfvén waves



Sun

speed decreses

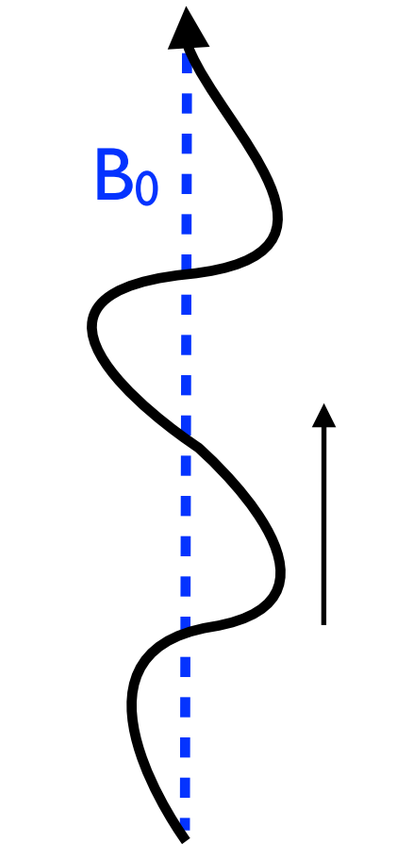


Sun

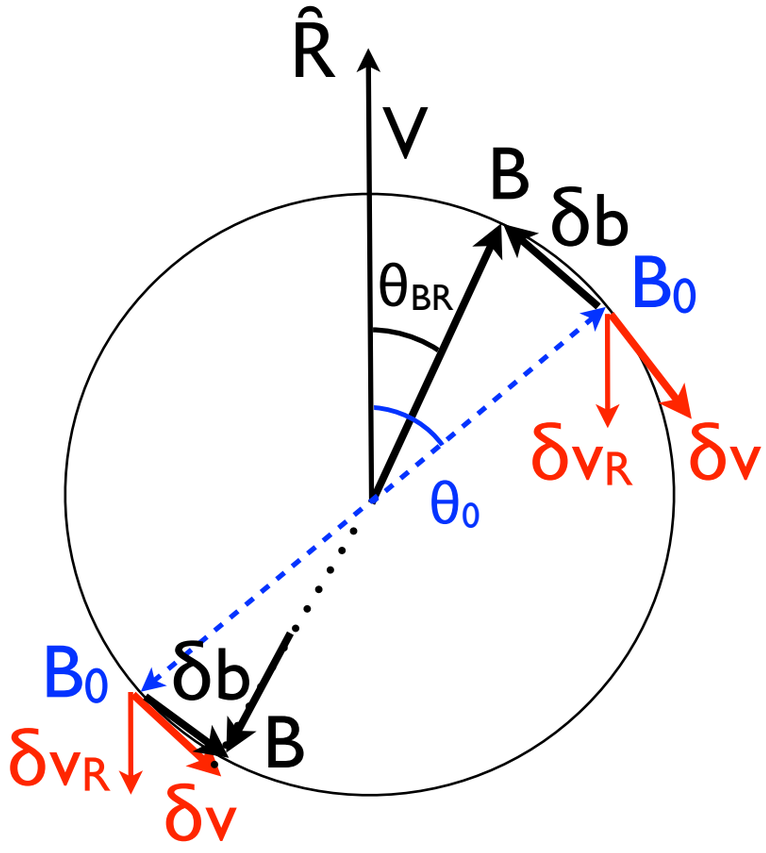
speed increases

A simple model of Alfvénic fluctuations

|**B**|=constant

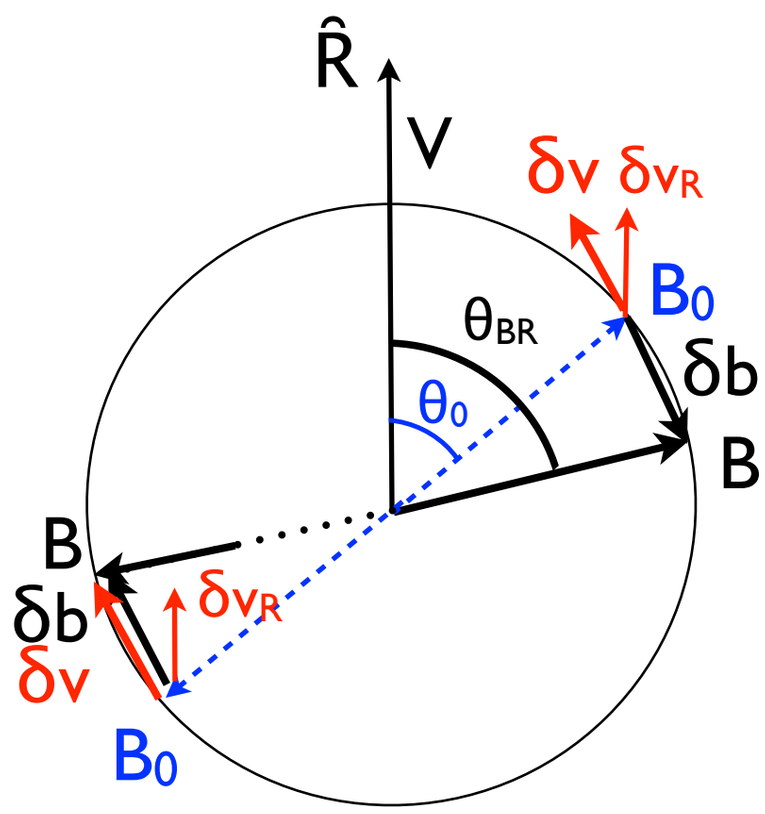


Alfvén waves



Sun

speed decreses

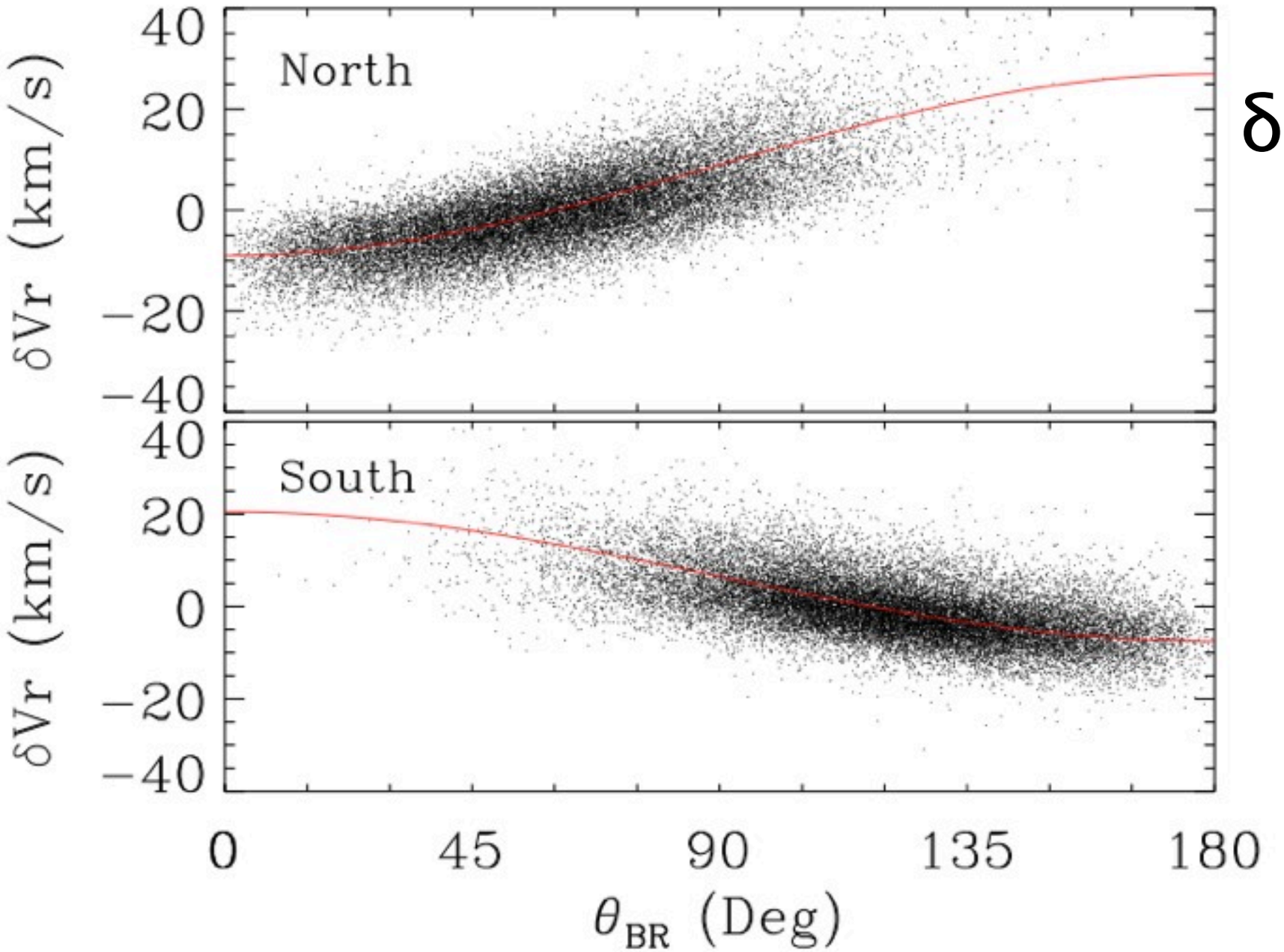


Sun

speed increases

$$V_{SW} = V_0 + \delta V_R = V_0 + V_A\,[1-\cos(\theta_{BR})]$$

Observed and predicted distribution of δV_R

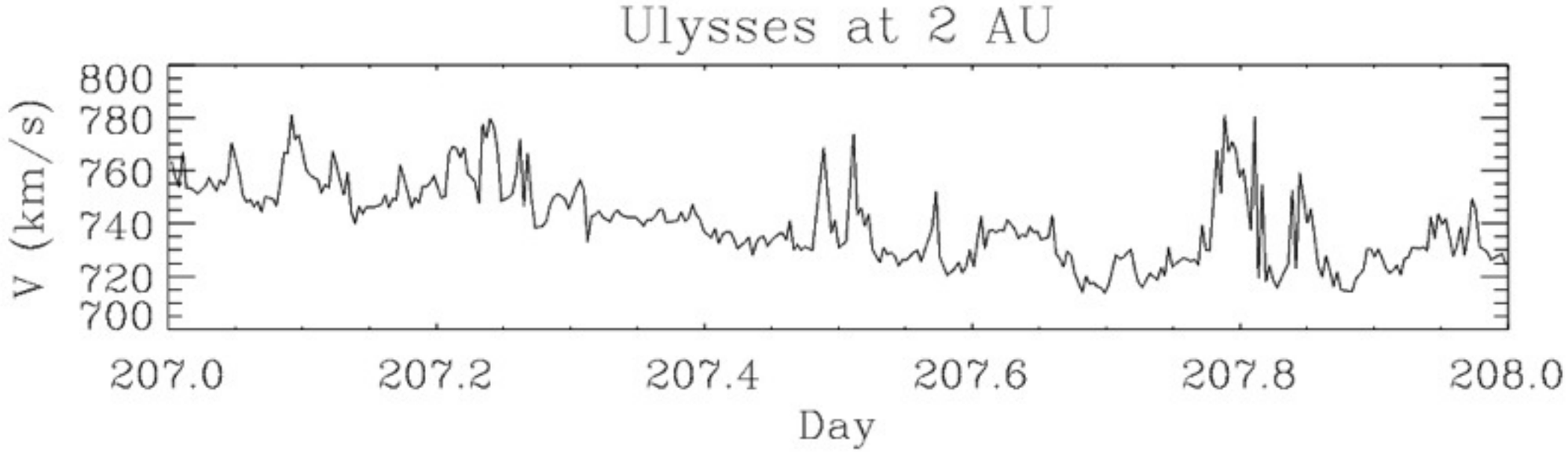


$\delta V_R \propto V_A [1-\cos(\theta_{BR})]$

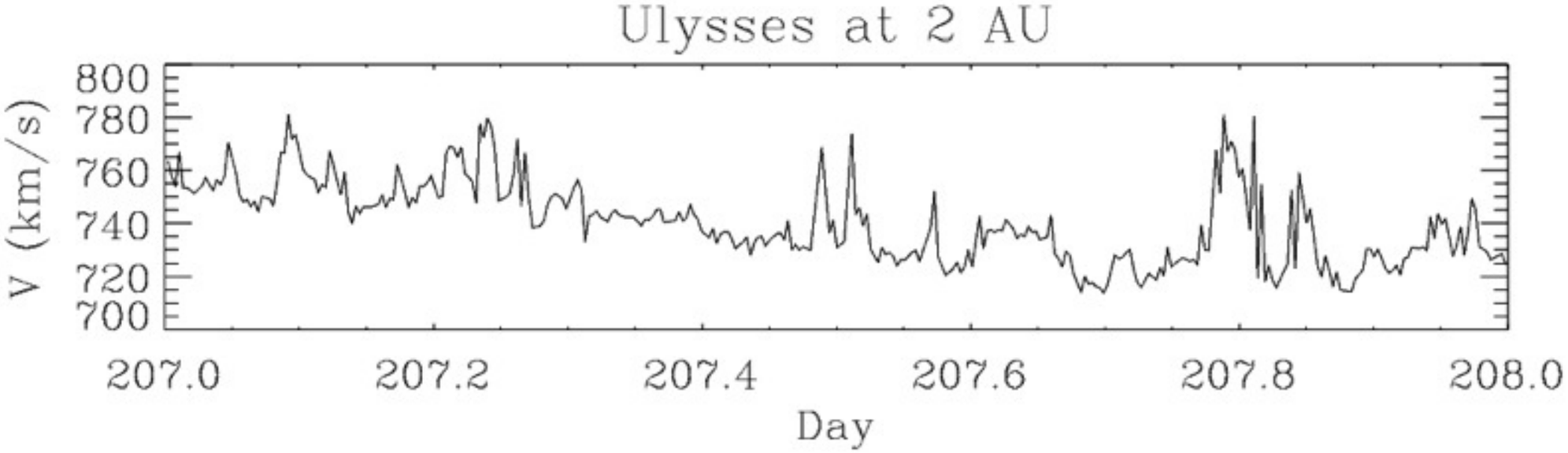
Resulting profile is not uniform... peaks!

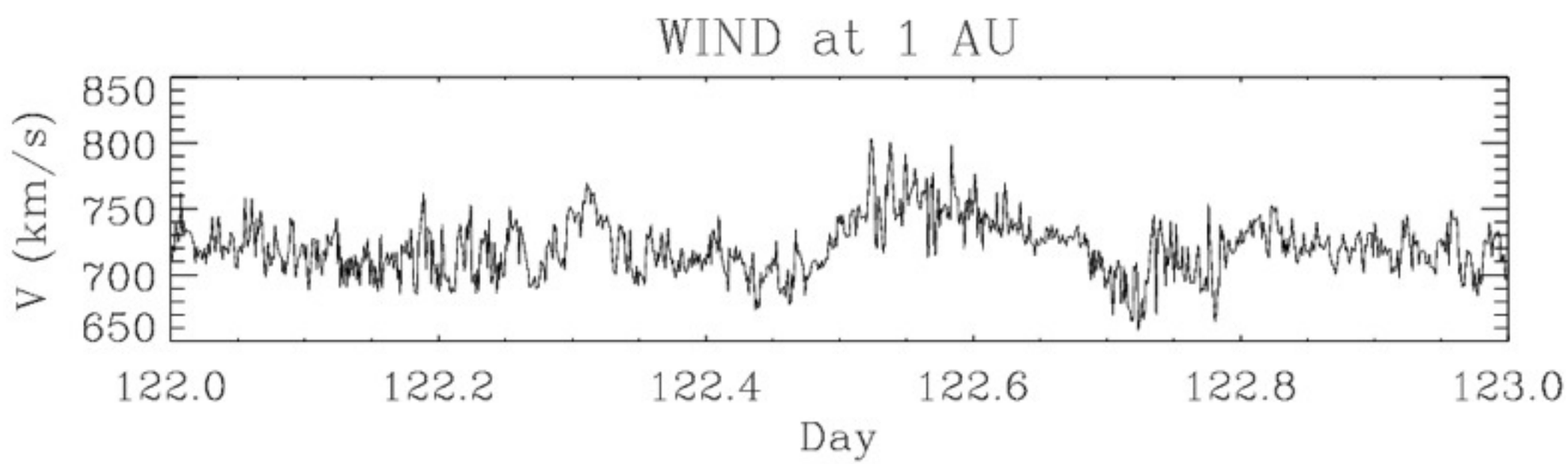
Matteini et al, GRL 2014

Typical fast wind profiles at different R

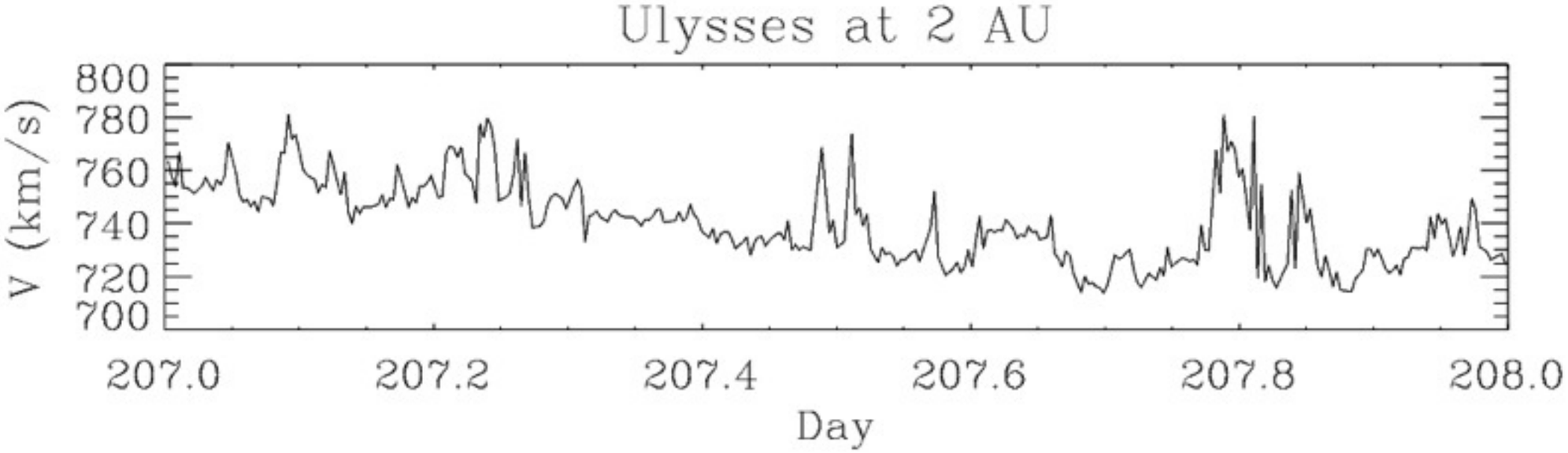


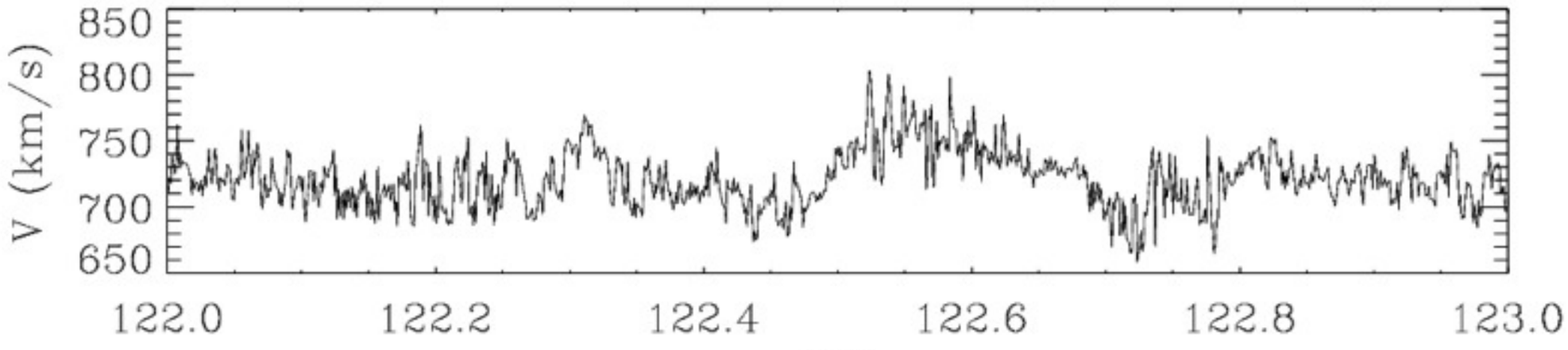
Typical fast wind profiles at different R

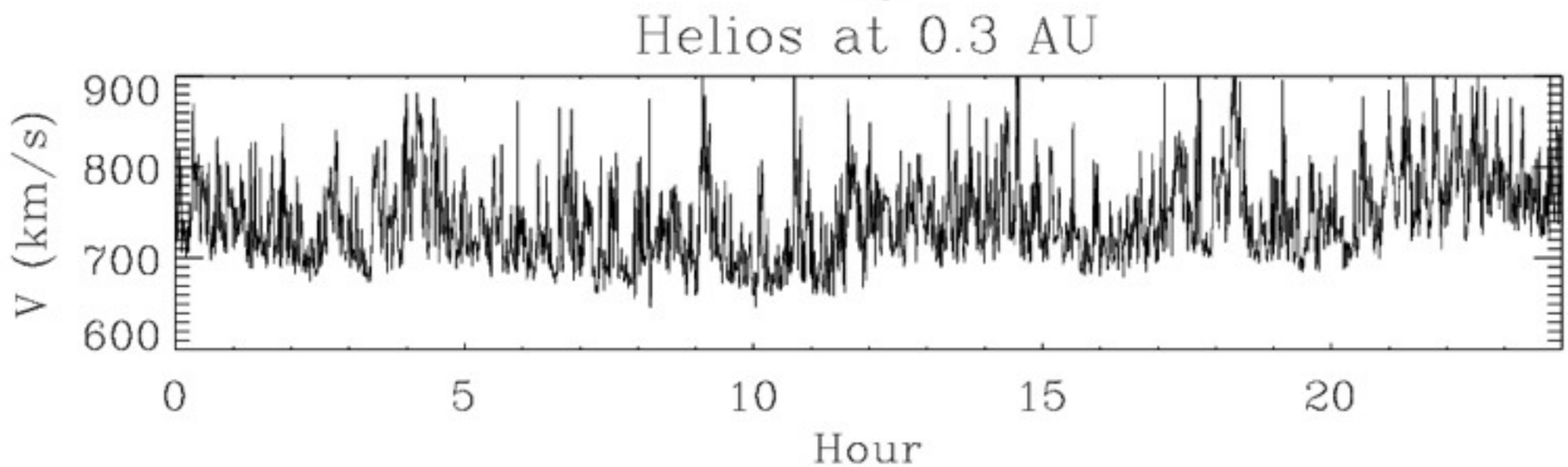




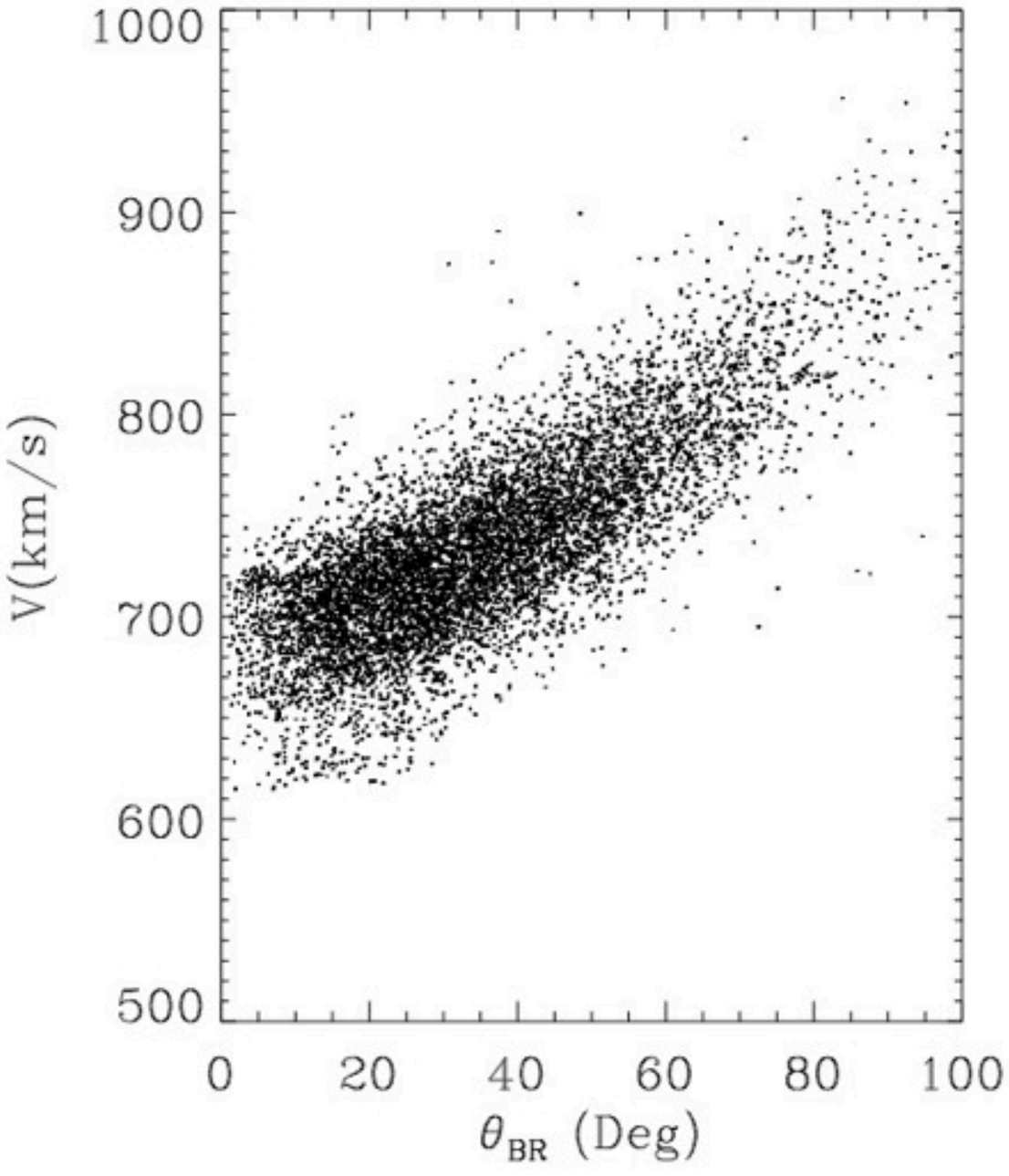
Typical fast wind profiles at different R





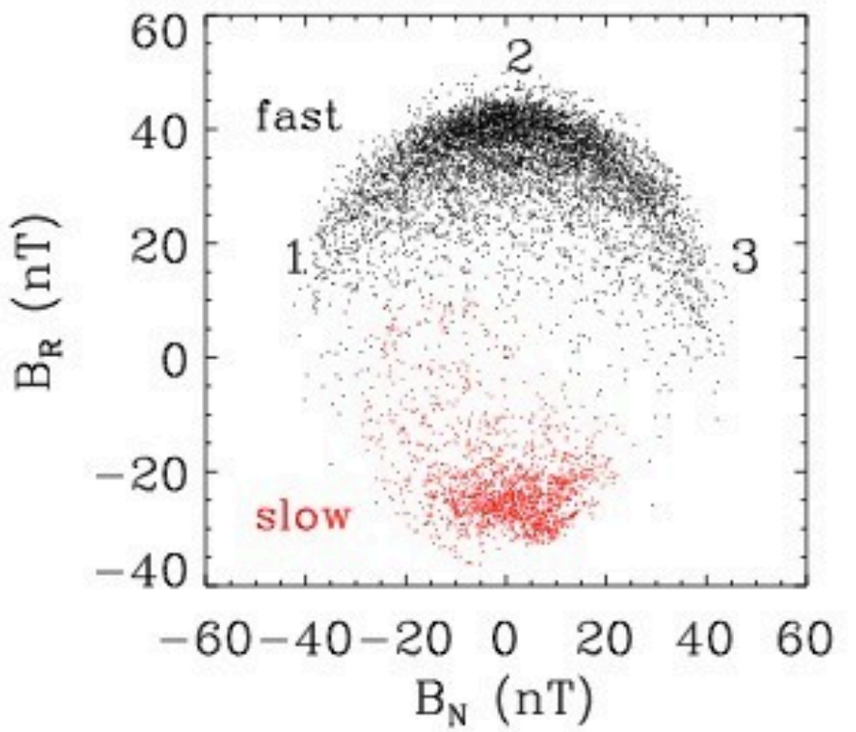


At 0.3 AU strong modulation of the speed



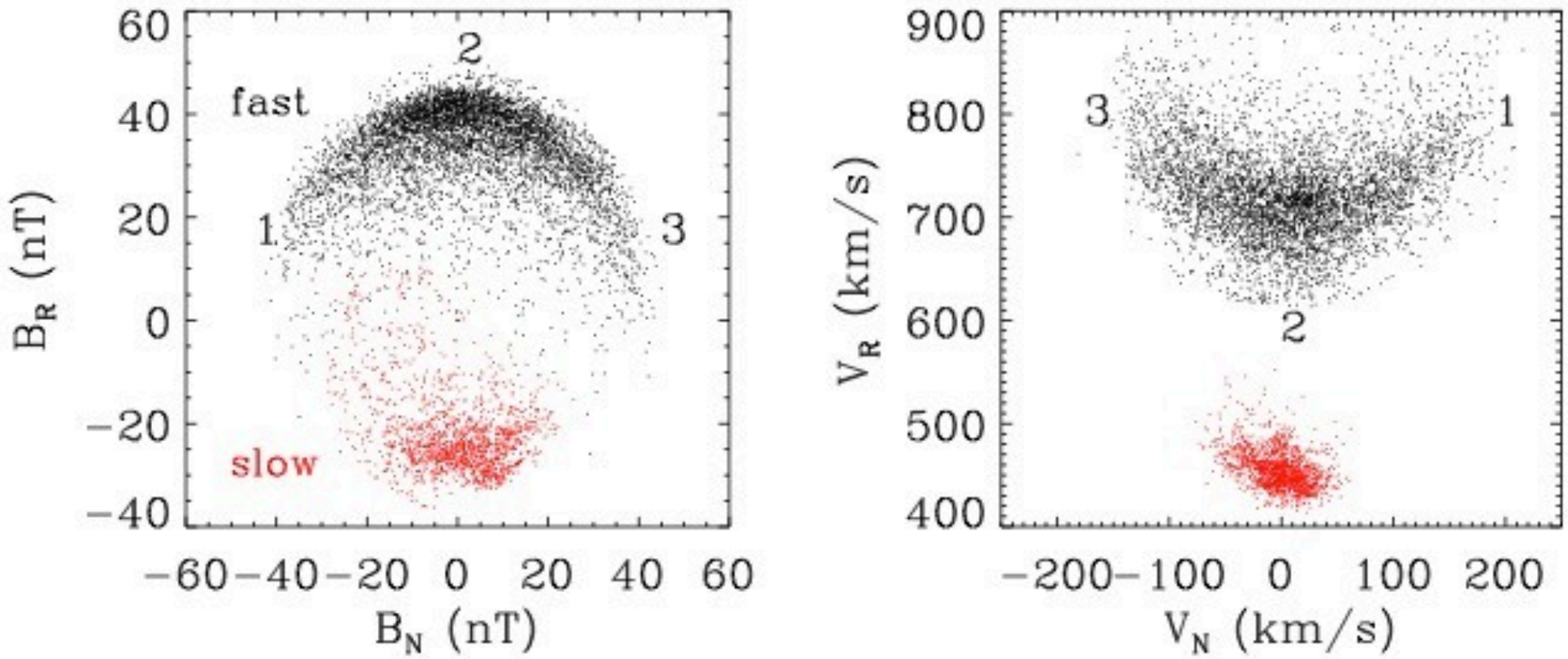
Matteini et al, ApJ 2015

Plasma motion and magnetic field rotation



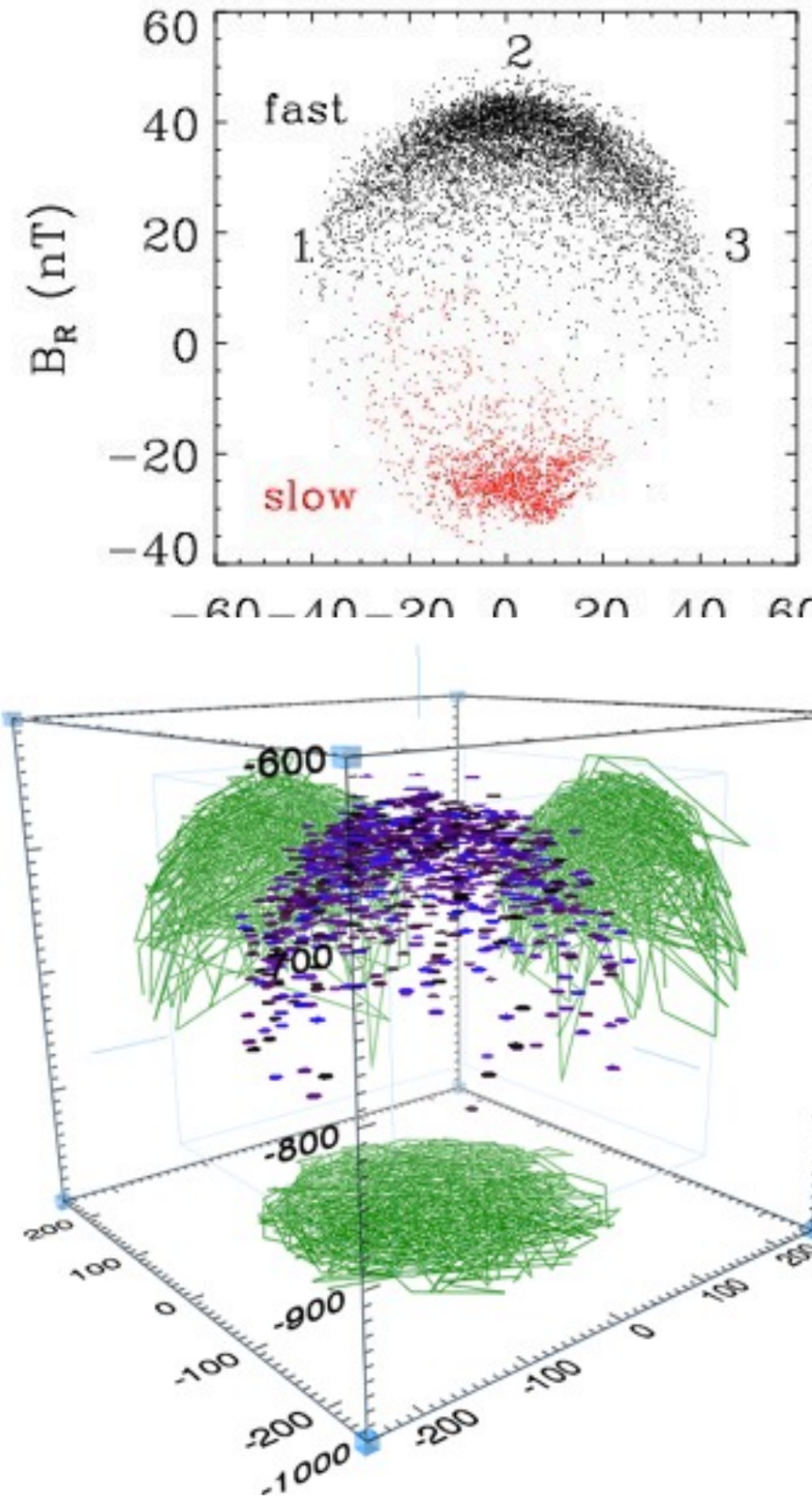
Matteini et al, ApJ 2015

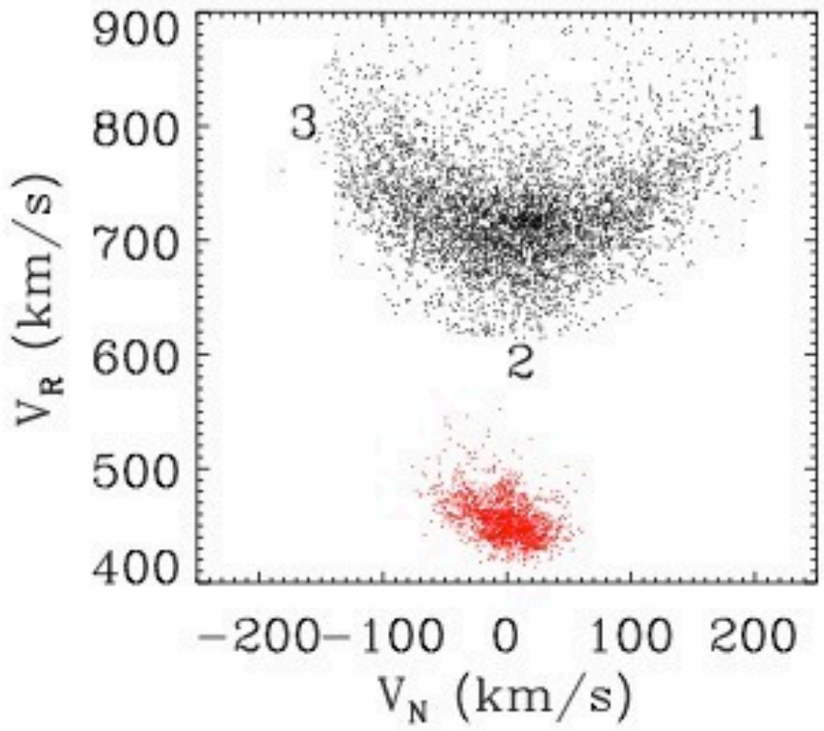
Plasma motion and magnetic field rotation



Matteini et al, ApJ 2015

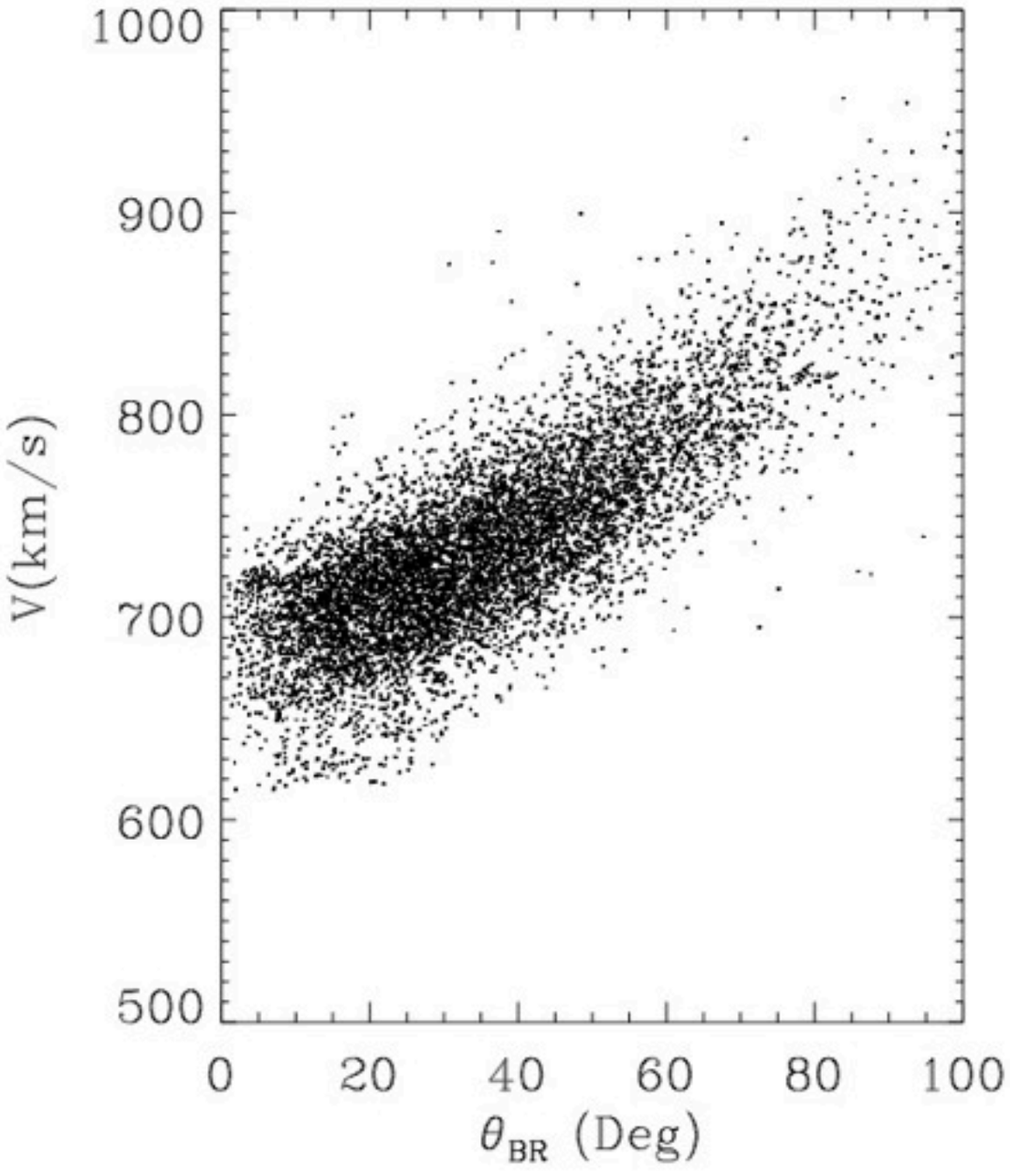
Plasma motion and magnetic field rotation



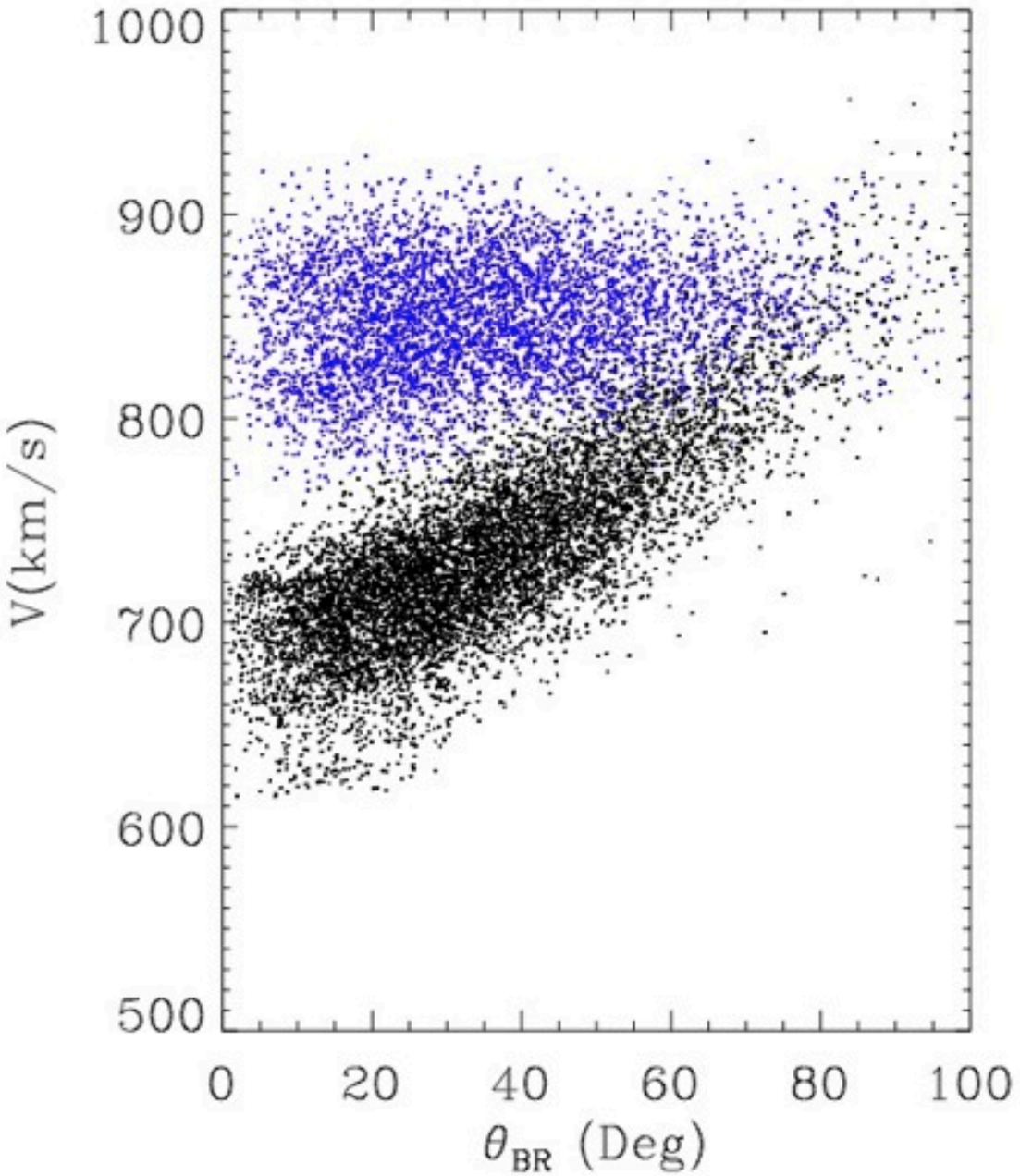


Matteini et al, ApJ 2015

At 0.3 AU strong modulation of the speed

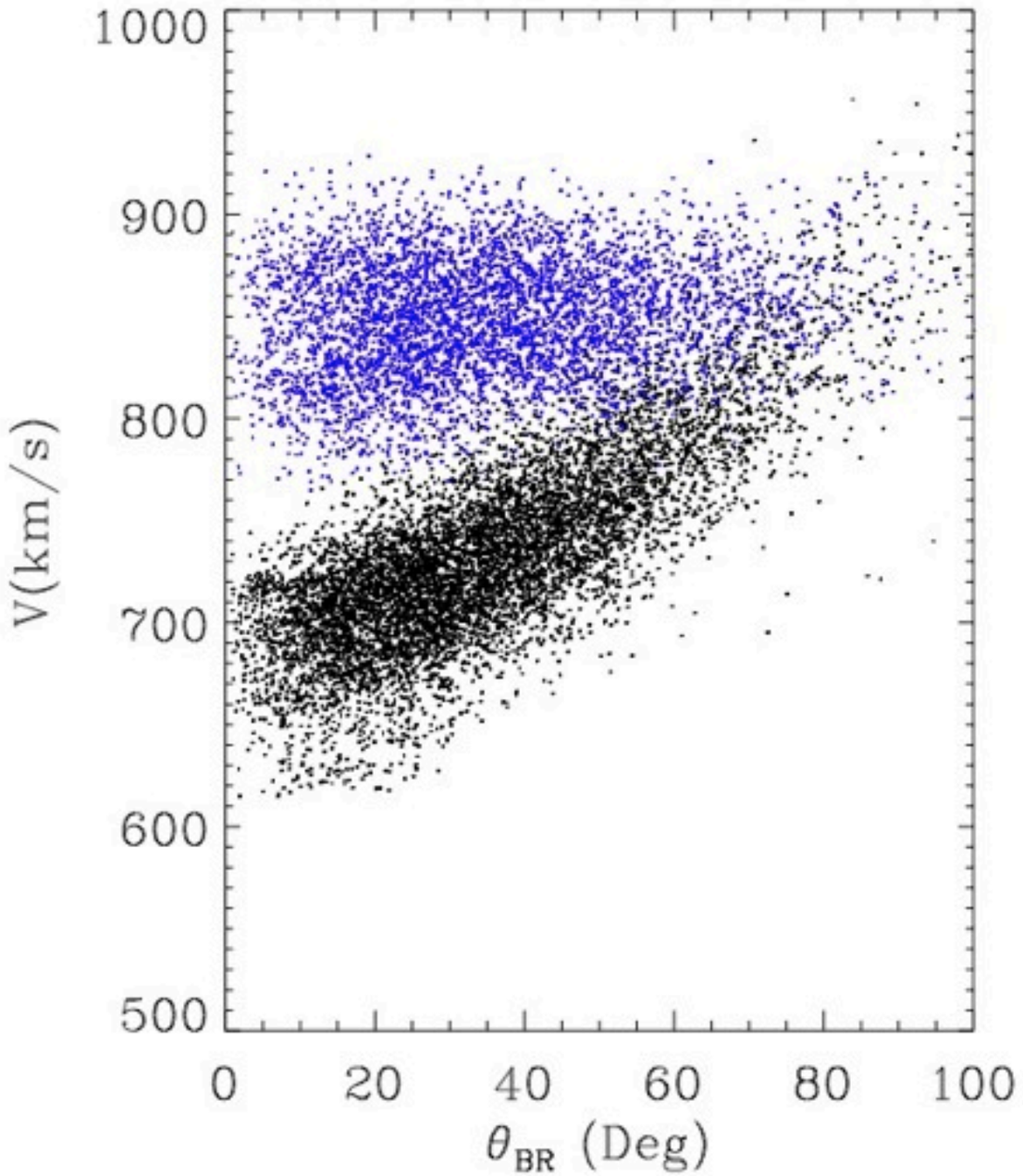


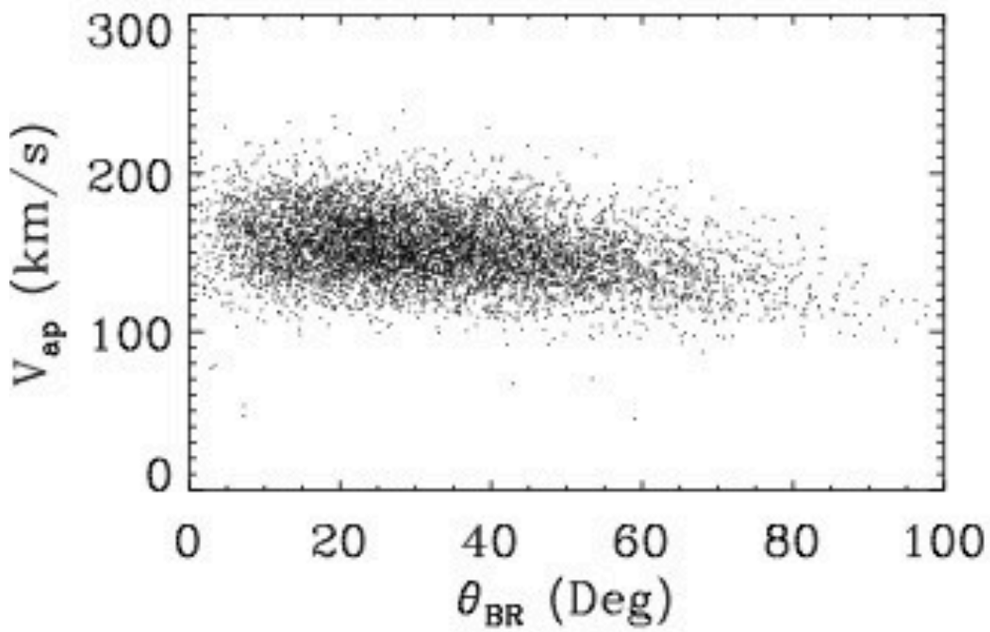
At 0.3 AU strong modulation of the speed



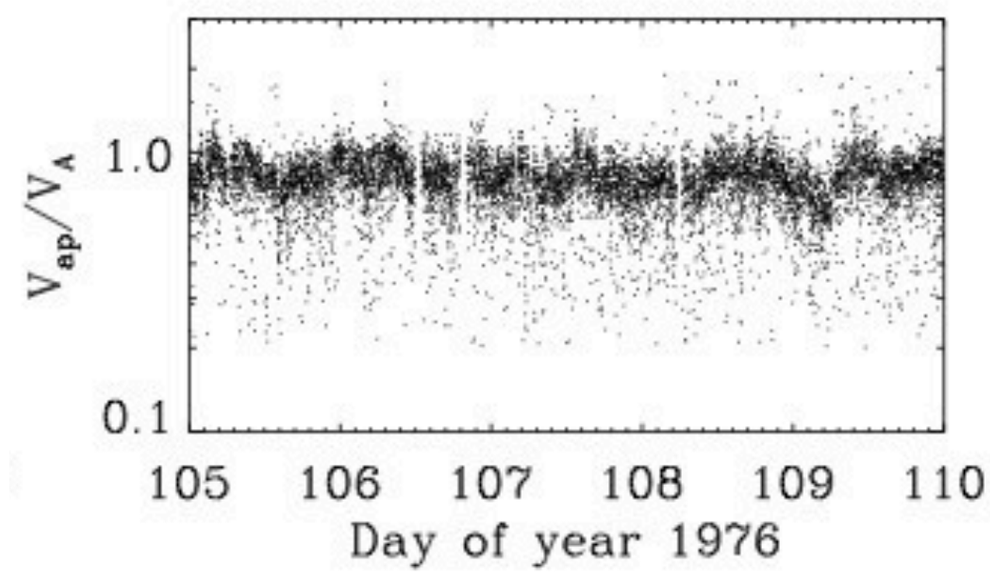
Speed of alphas is not modulated!
Alphas "surf" the turbulence

At 0.3 AU strong modulation of the speed





$|\mathbf{V}_p - \mathbf{V}_\alpha|$

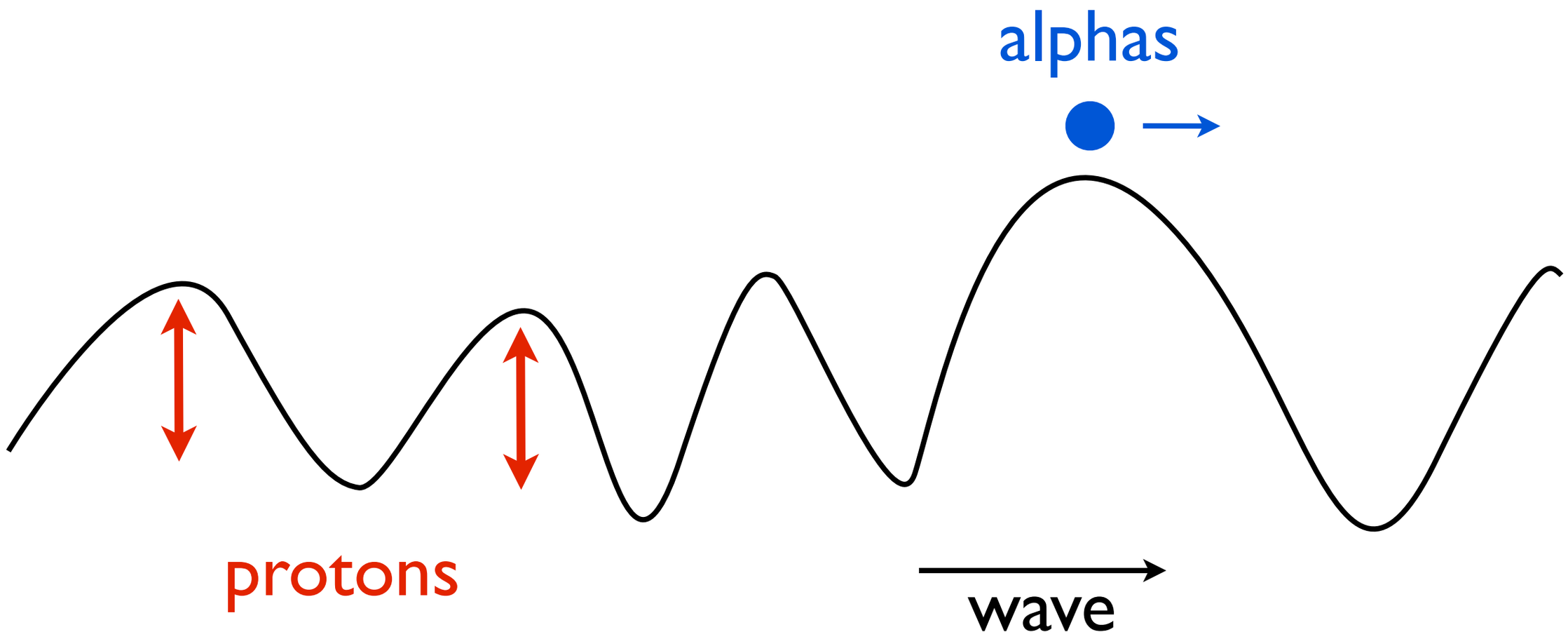


$\mathbf{V}_{\alpha p}/V_A$

Speed of alphas is not modulated!
Alphas "surf" the turbulence

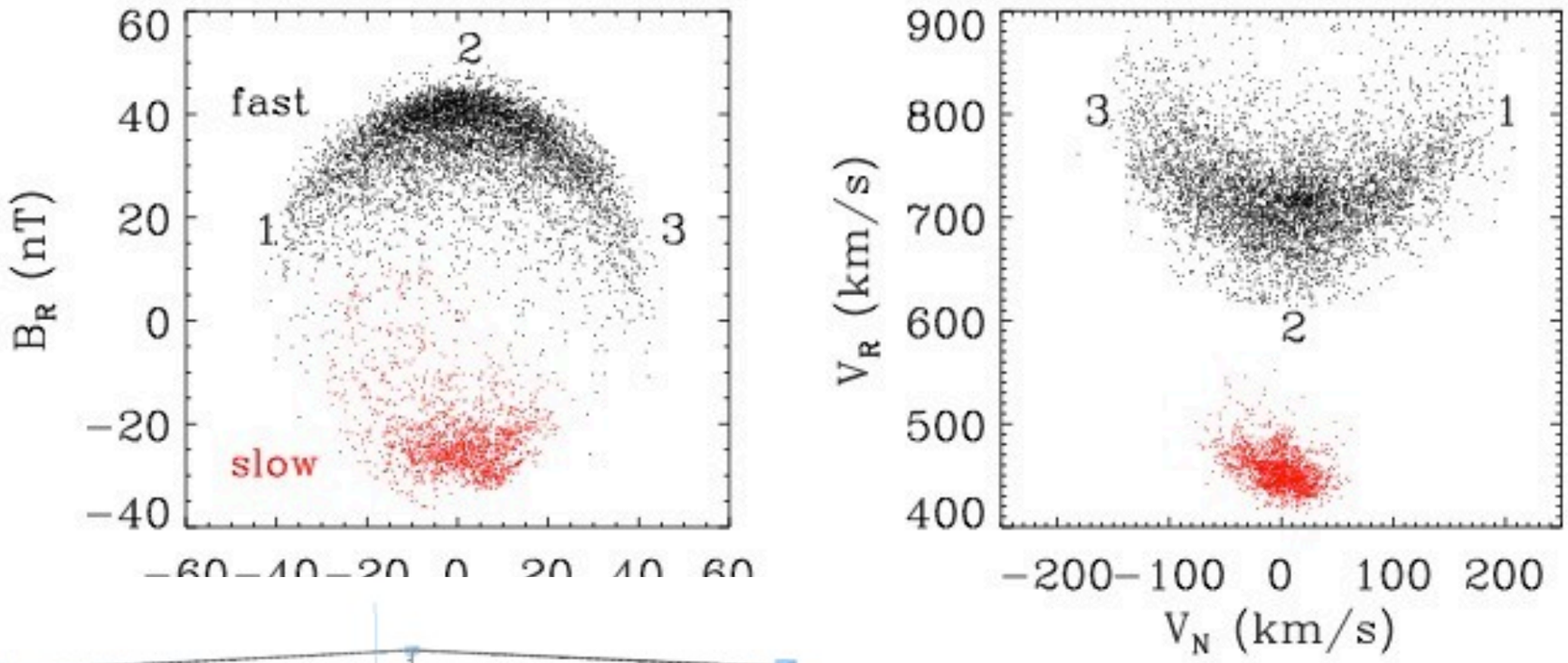
alpha-proton drift is constant
(velocities are not aligned)

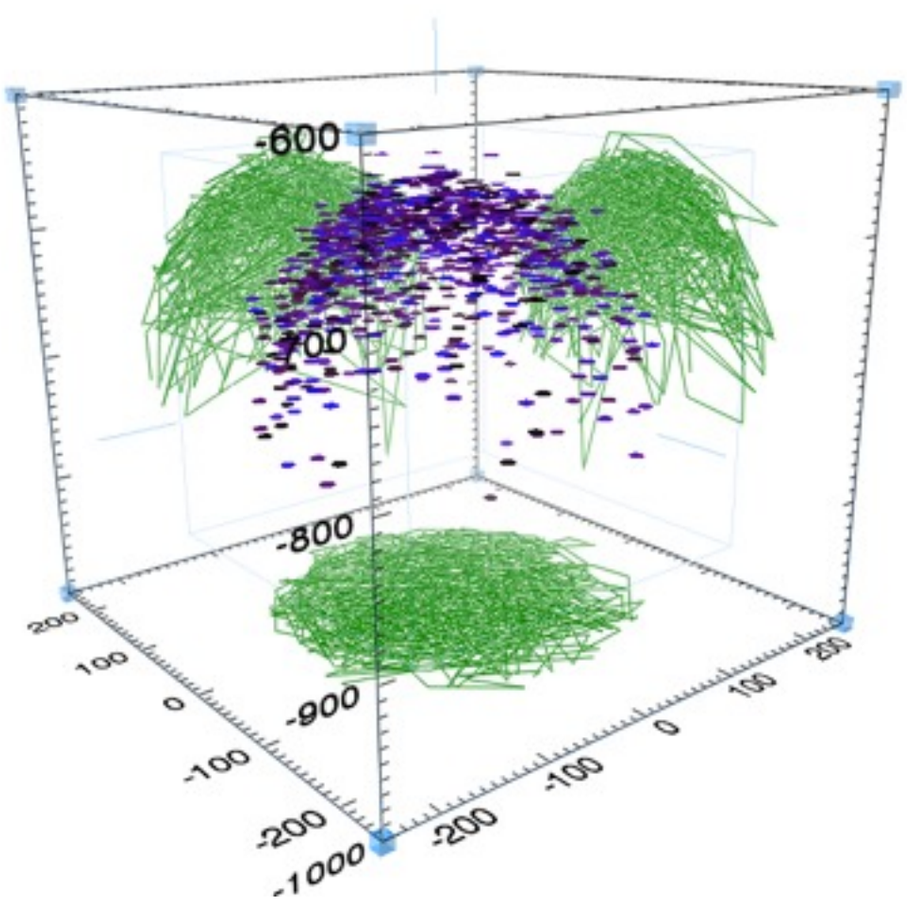
Alpha particles surf the turbulence



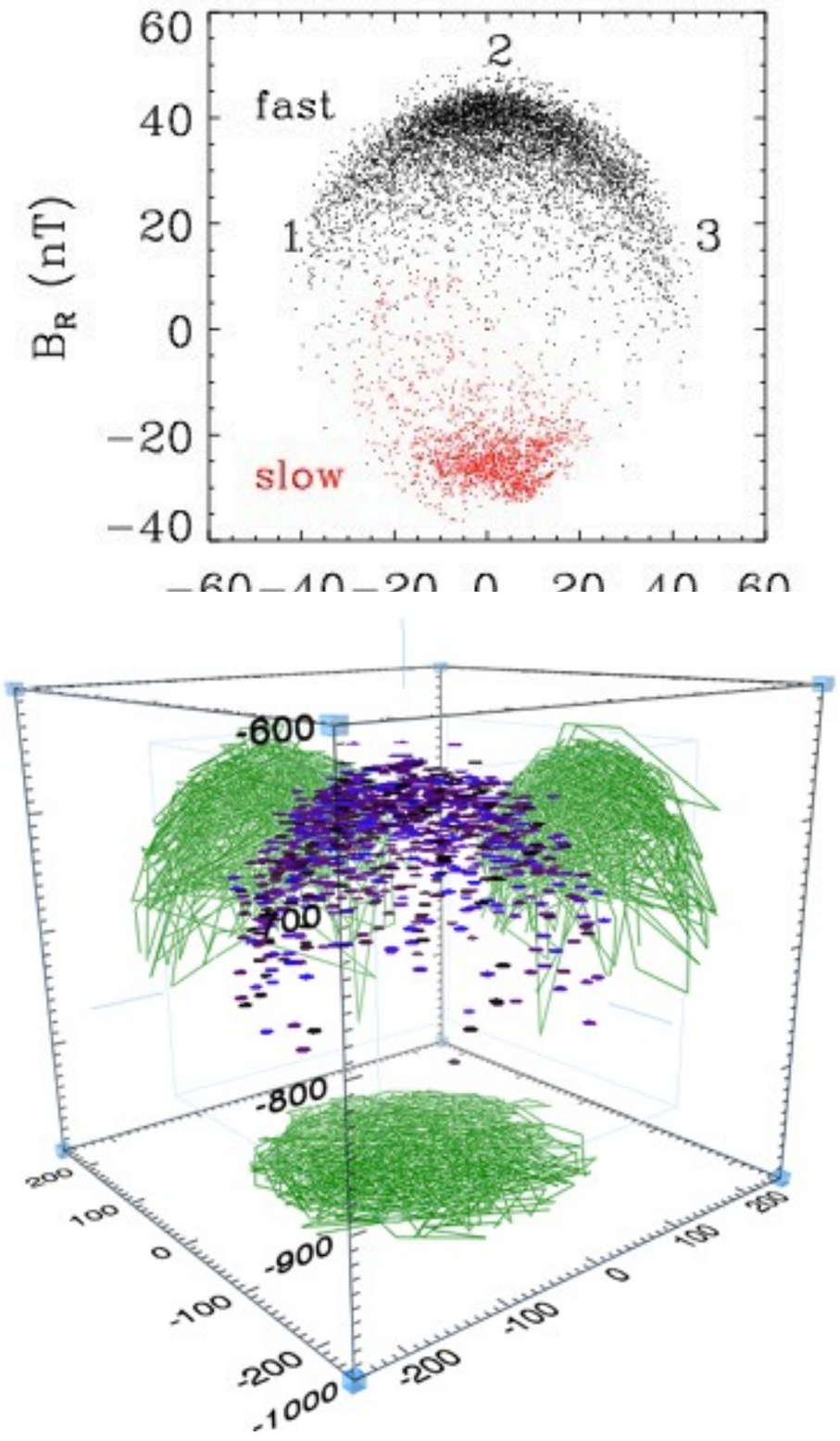
Alphas stream in phase with the fluctuations
and thus do not oscillate!

Plasma motion and magnetic field rotation

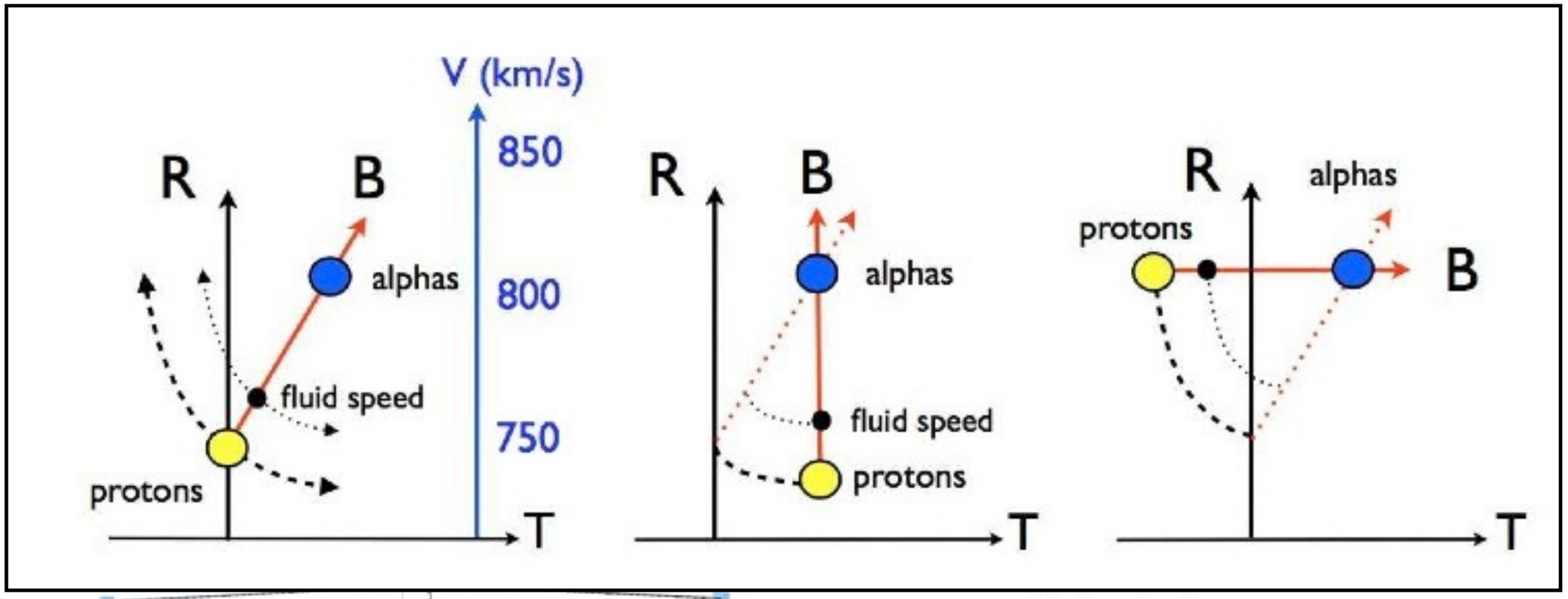


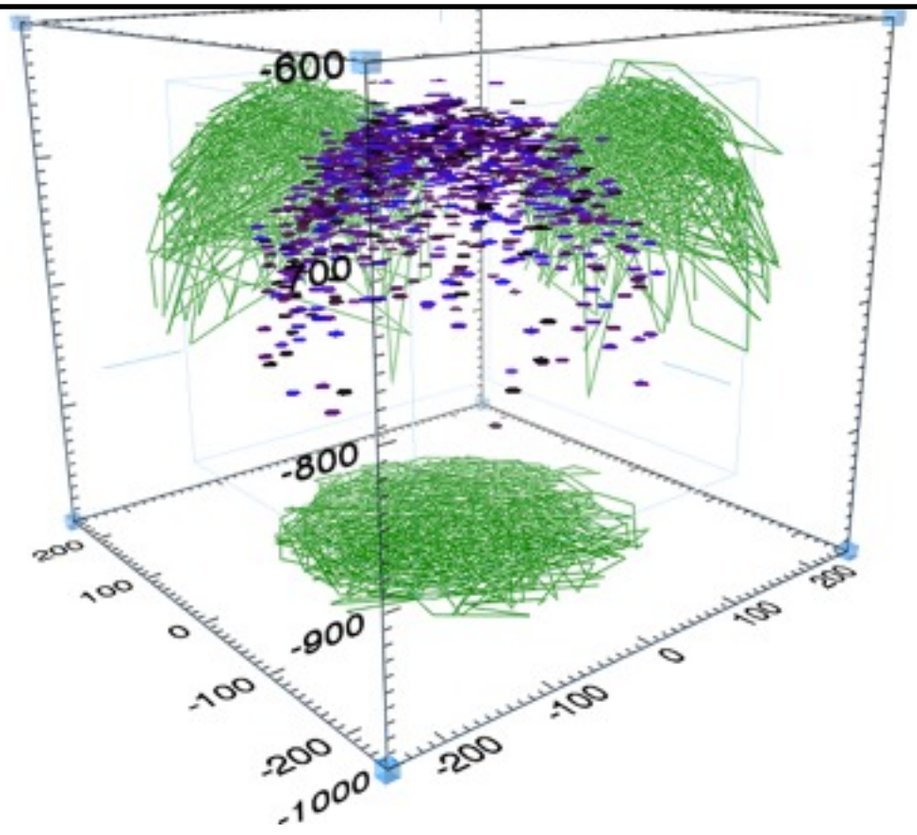


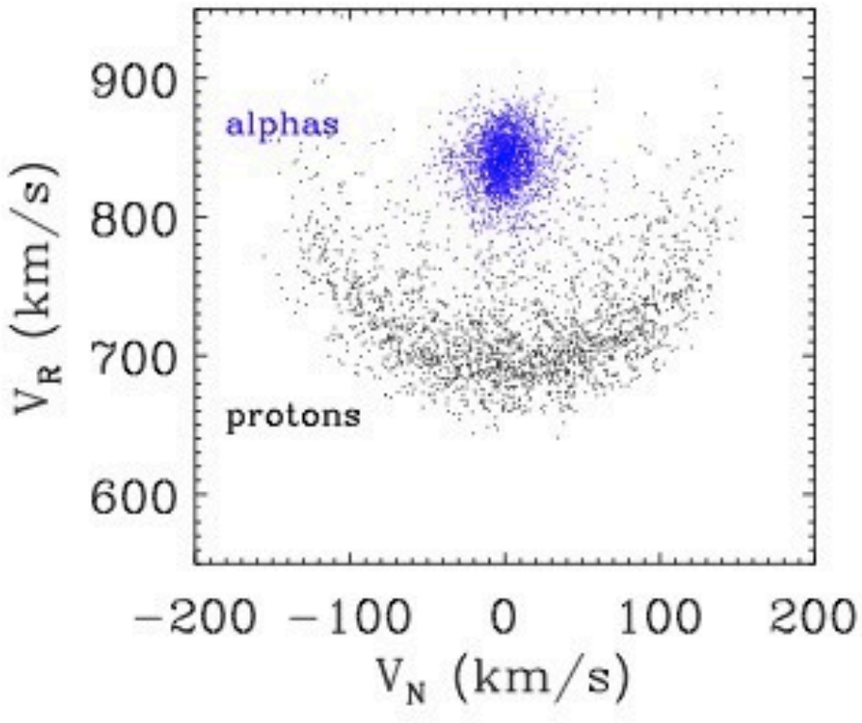
Plasma motion and magnetic field rotation



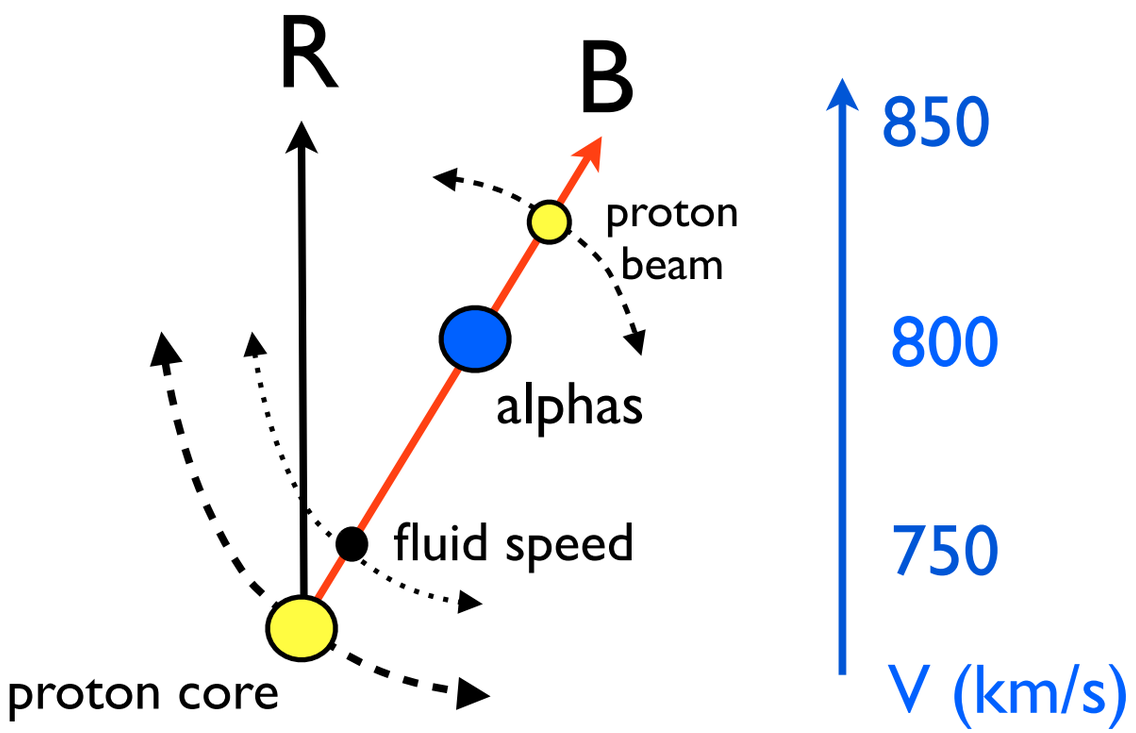
Plasma motion and magnetic field rotation

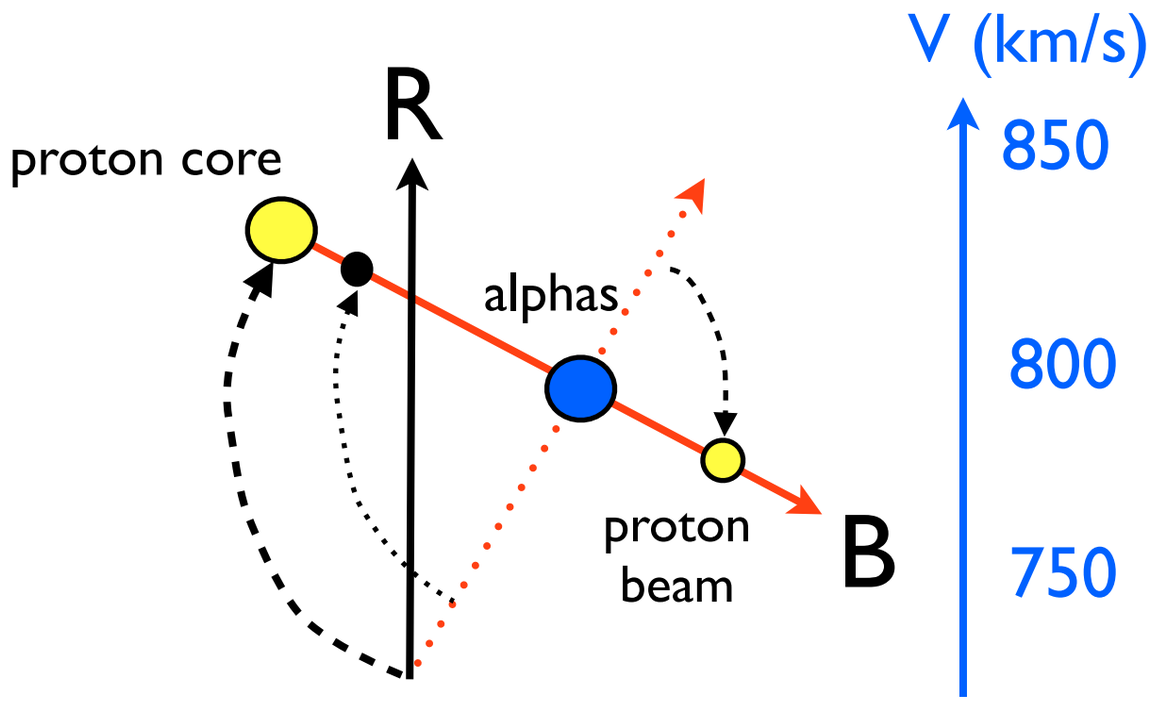






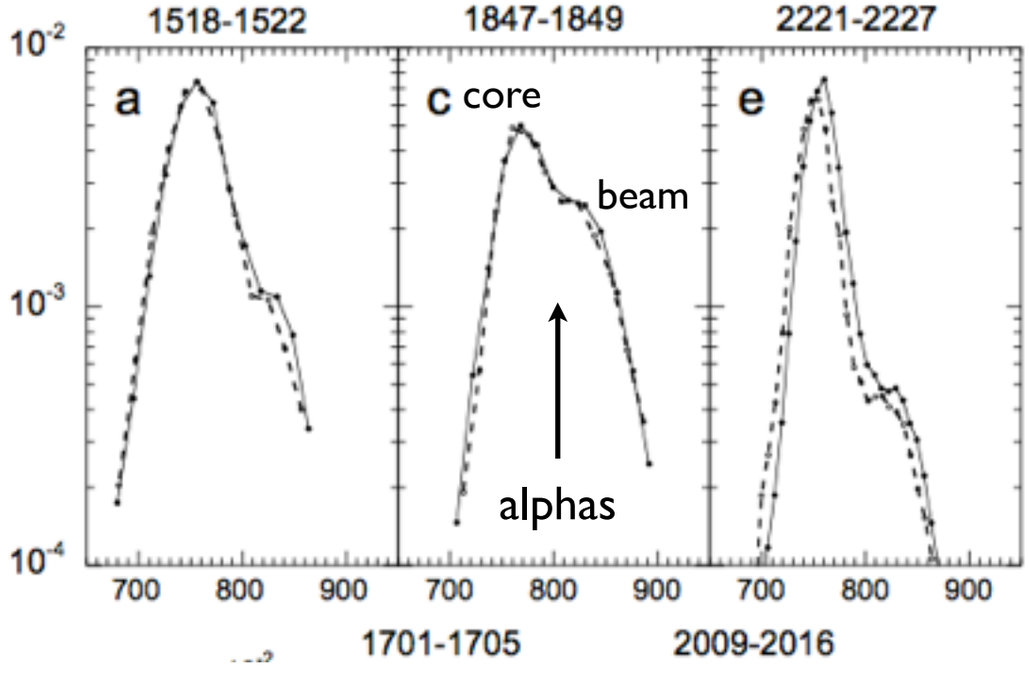
Switchbacks

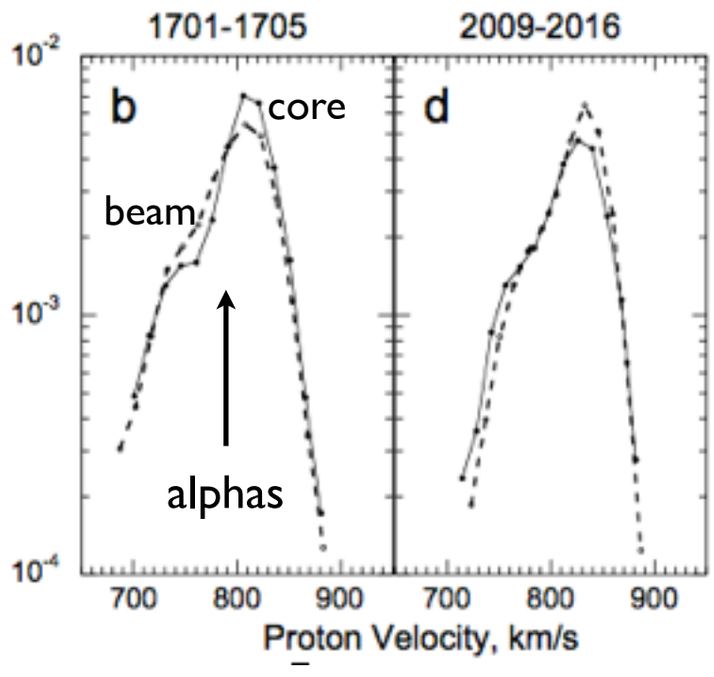


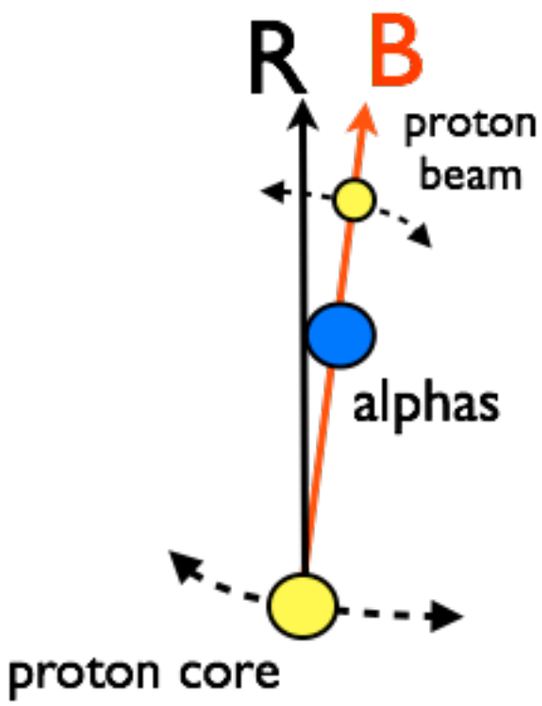


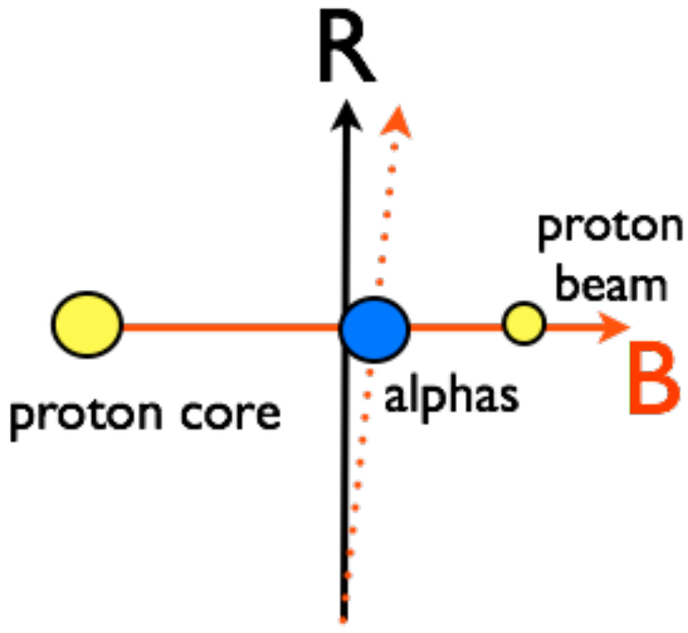
Proton beams oscillate in anti-phase with proton cores since usually: $V_b > V_A \sim V_\alpha$

When rotation of B is >90 core-beam is reversed and core protons are faster than alphas






R
B
proton
beam
alphas
proton core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proton
beam
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proton core
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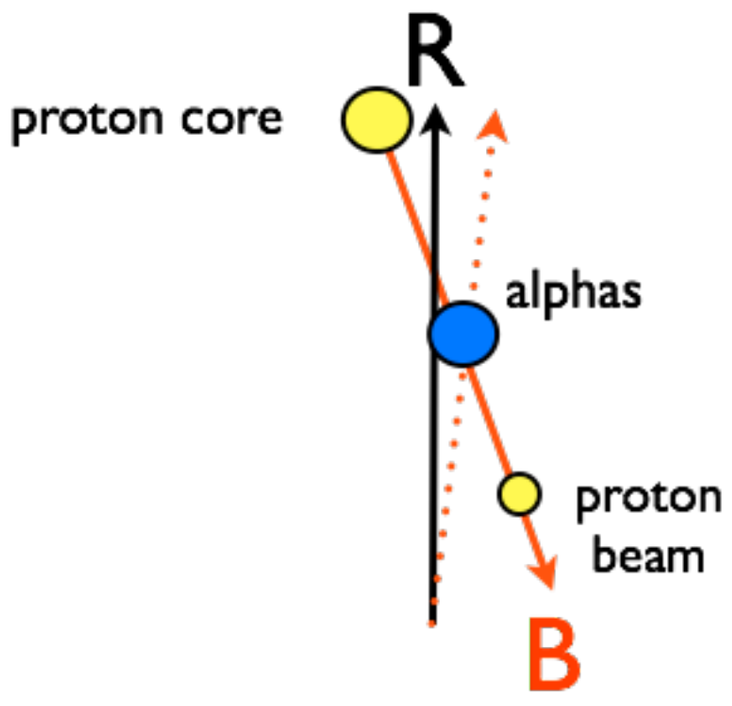
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proton core
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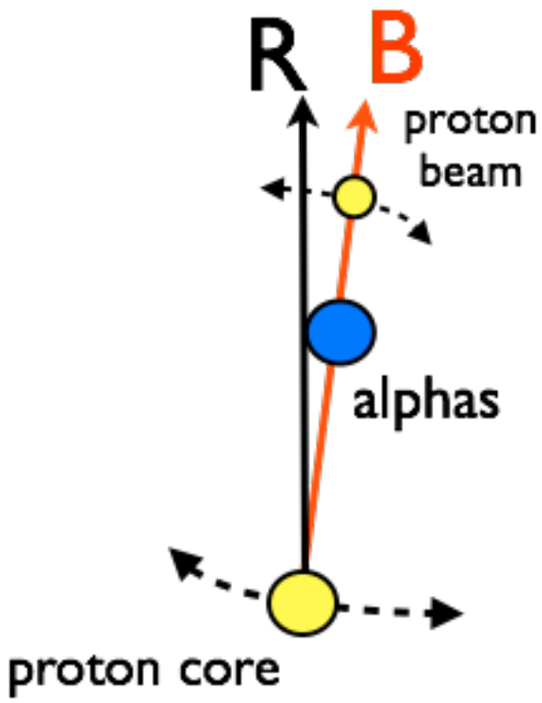
proton
beam
B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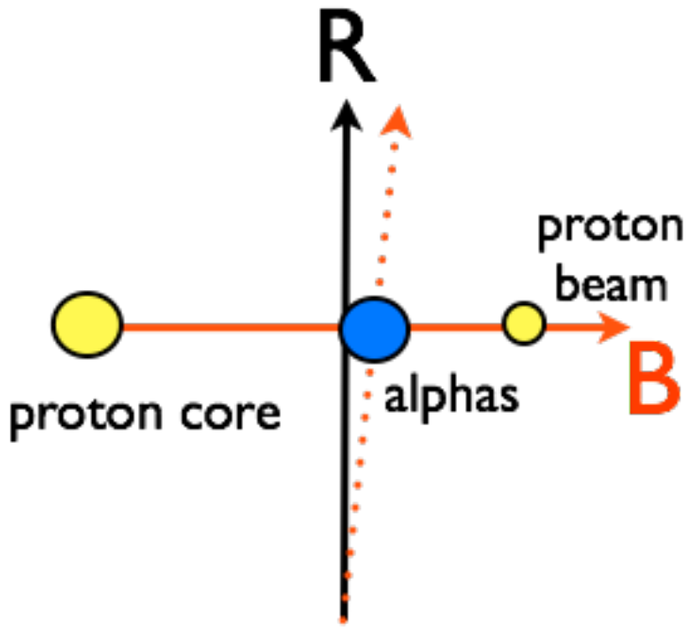
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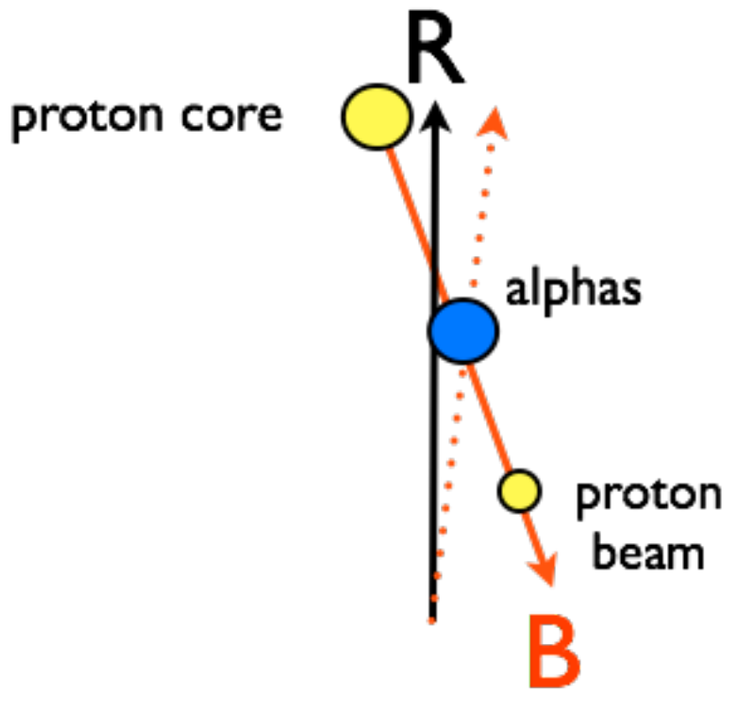
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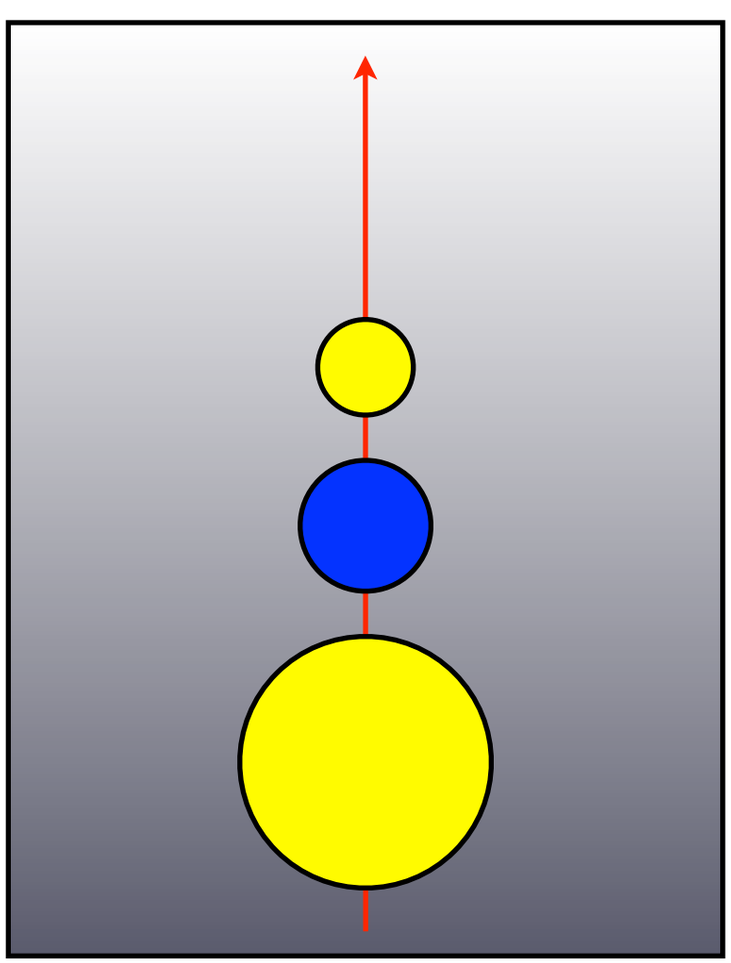

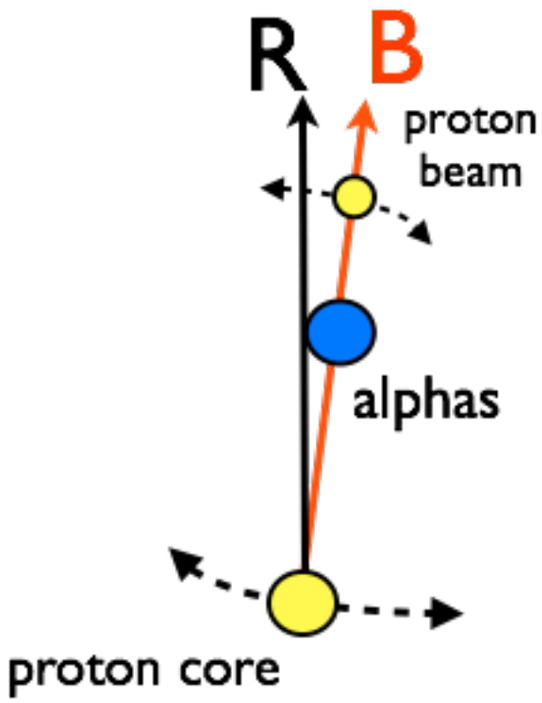
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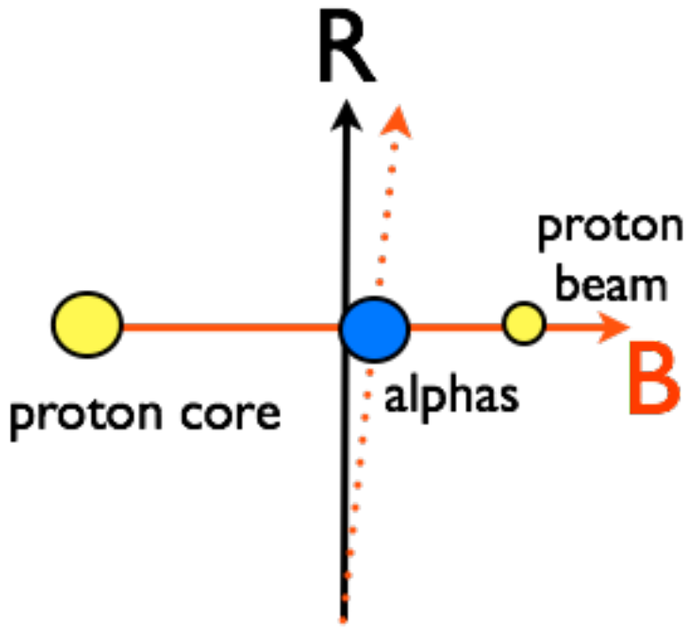
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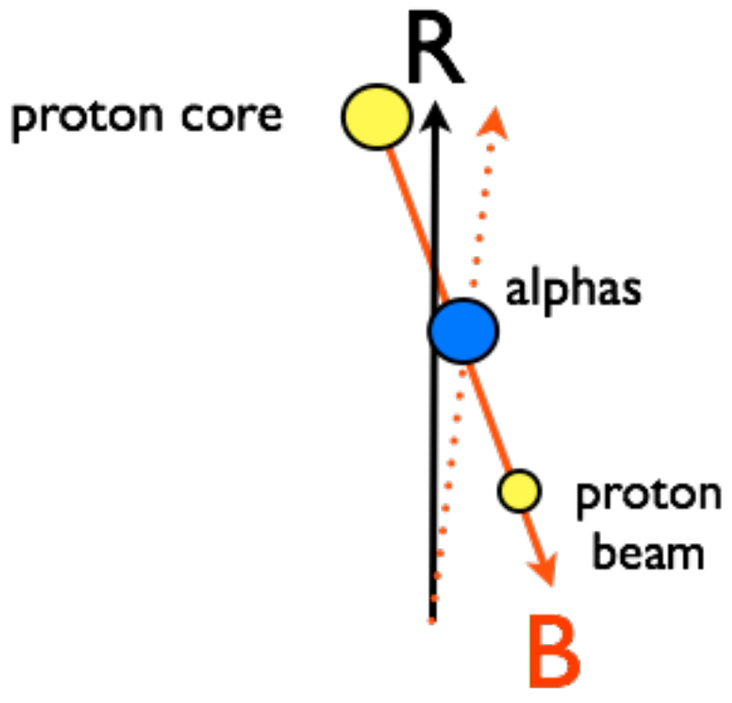
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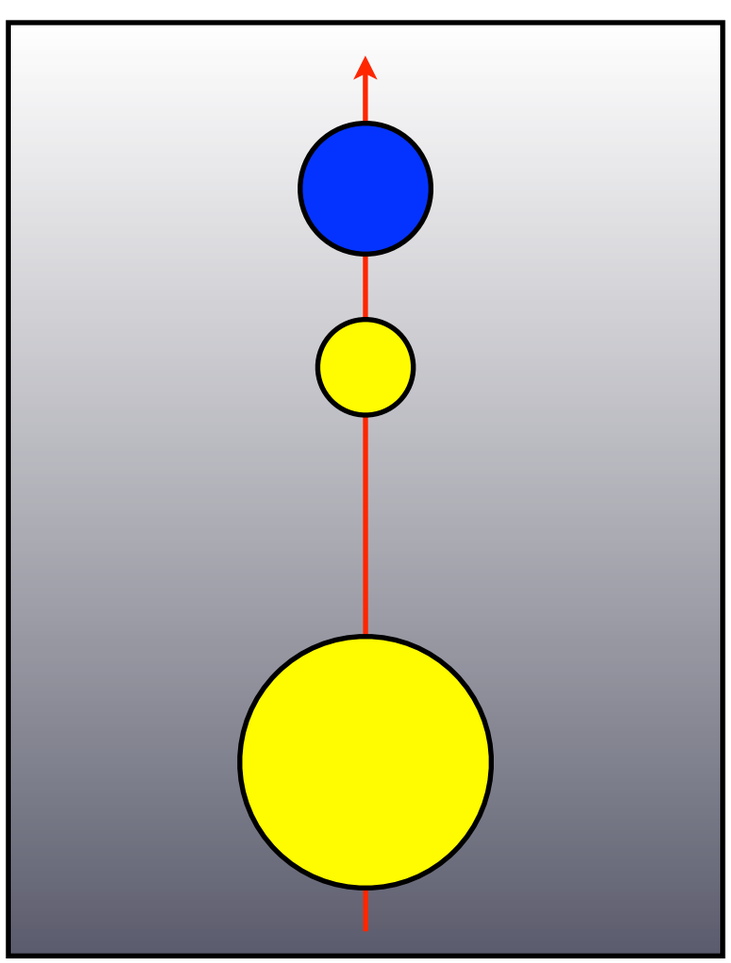

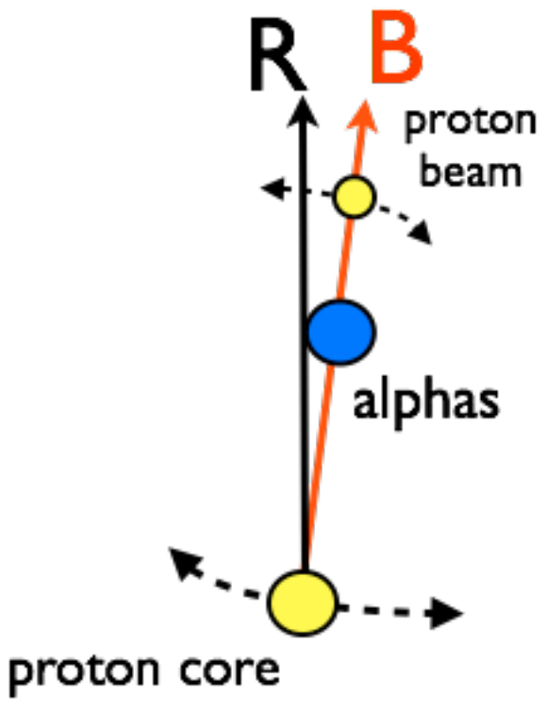
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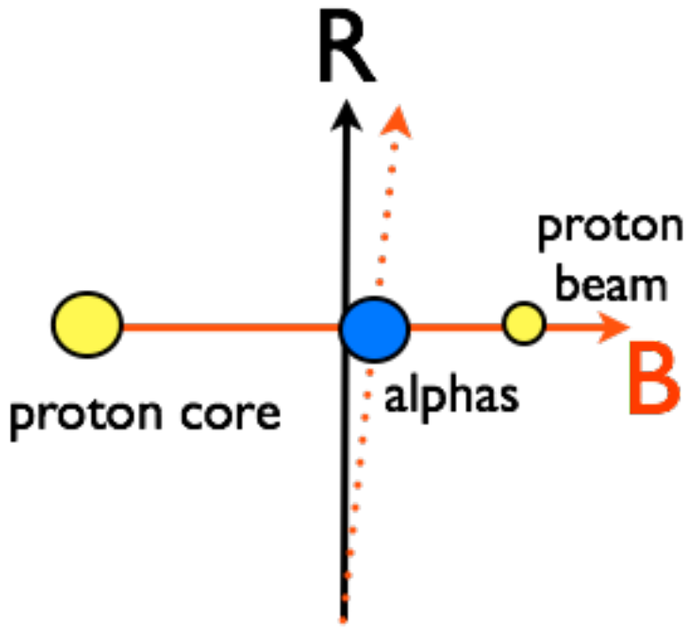
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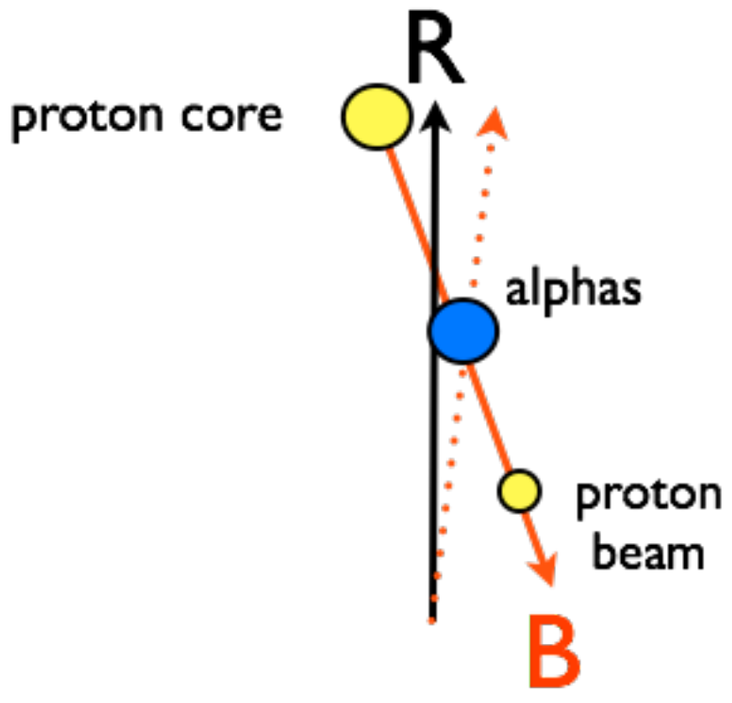
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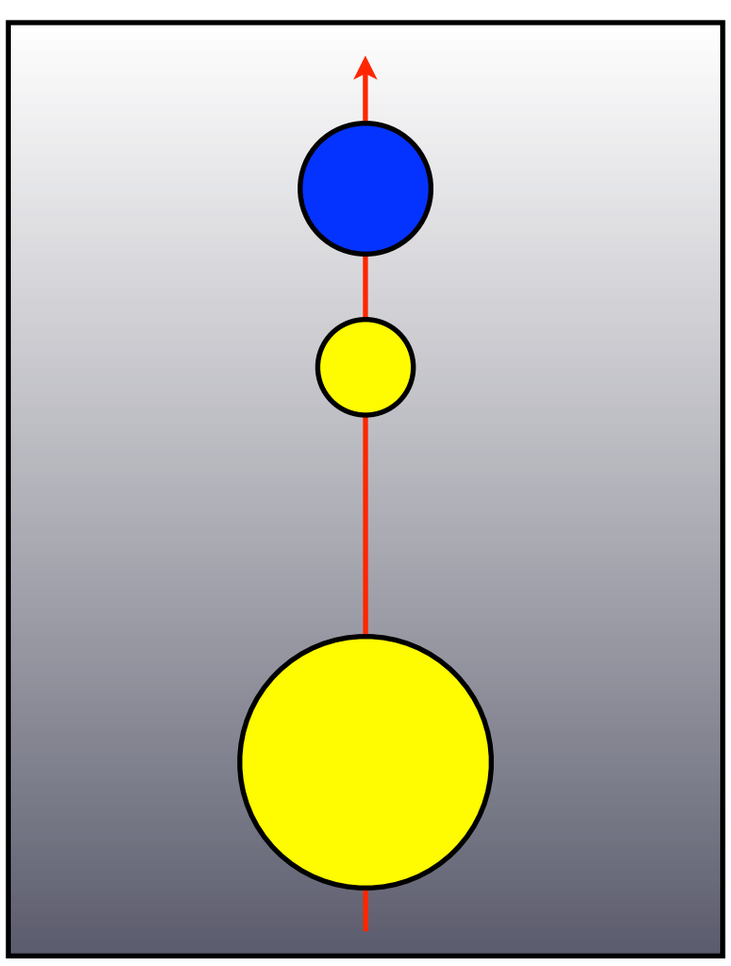

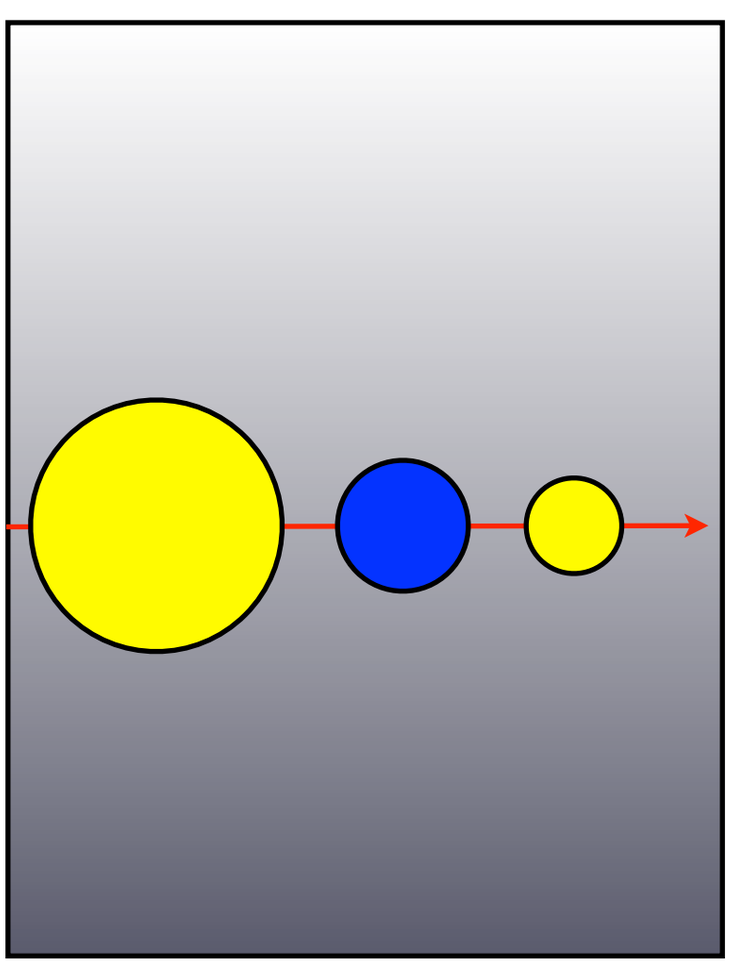

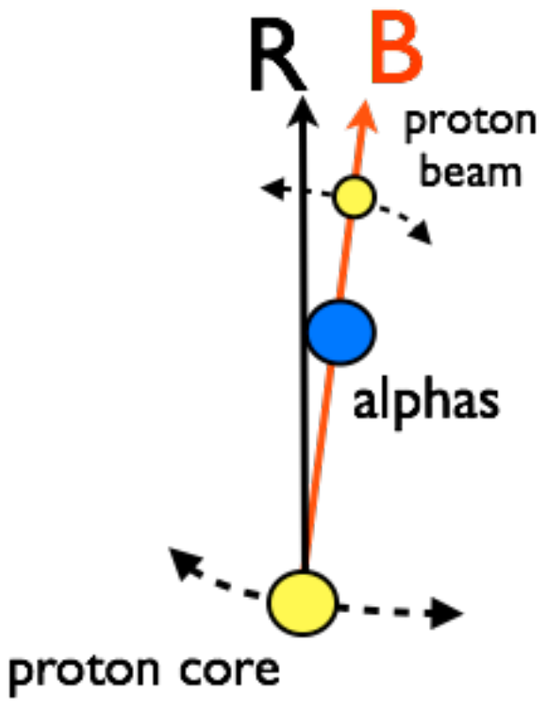
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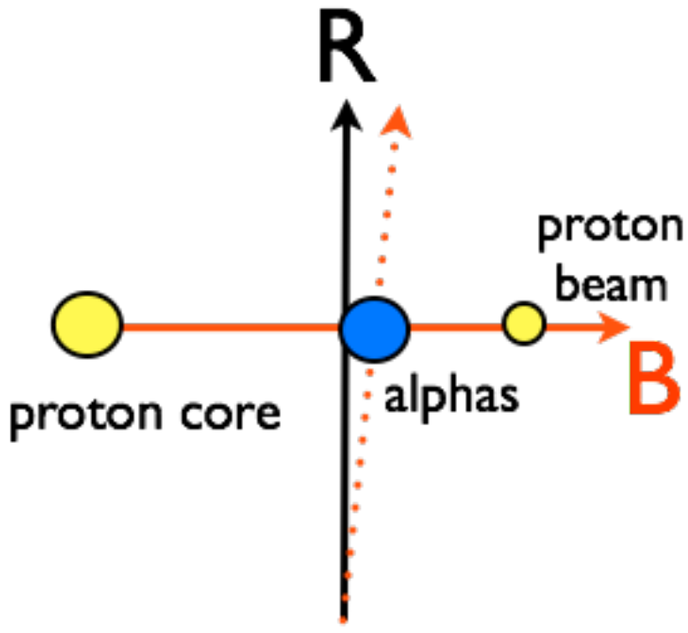
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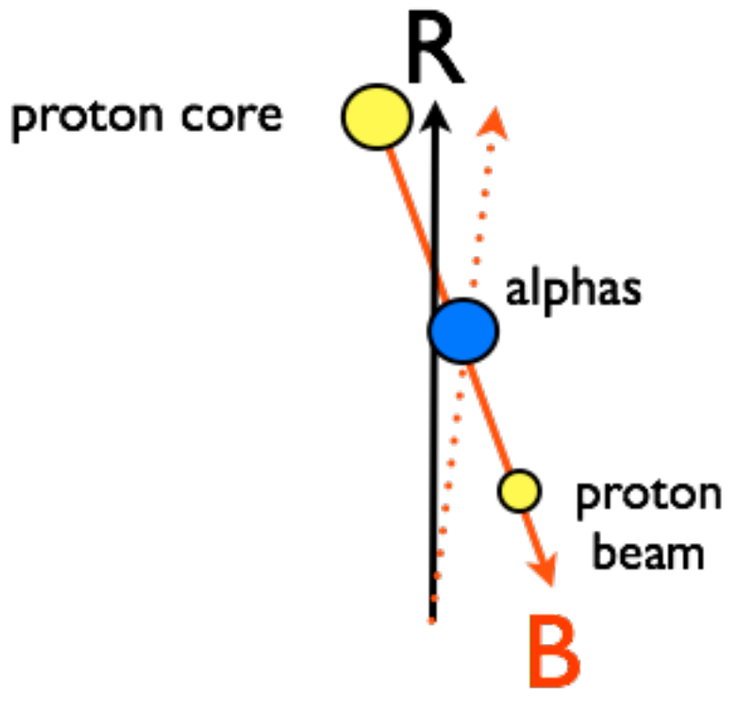
R
proton core
alphas
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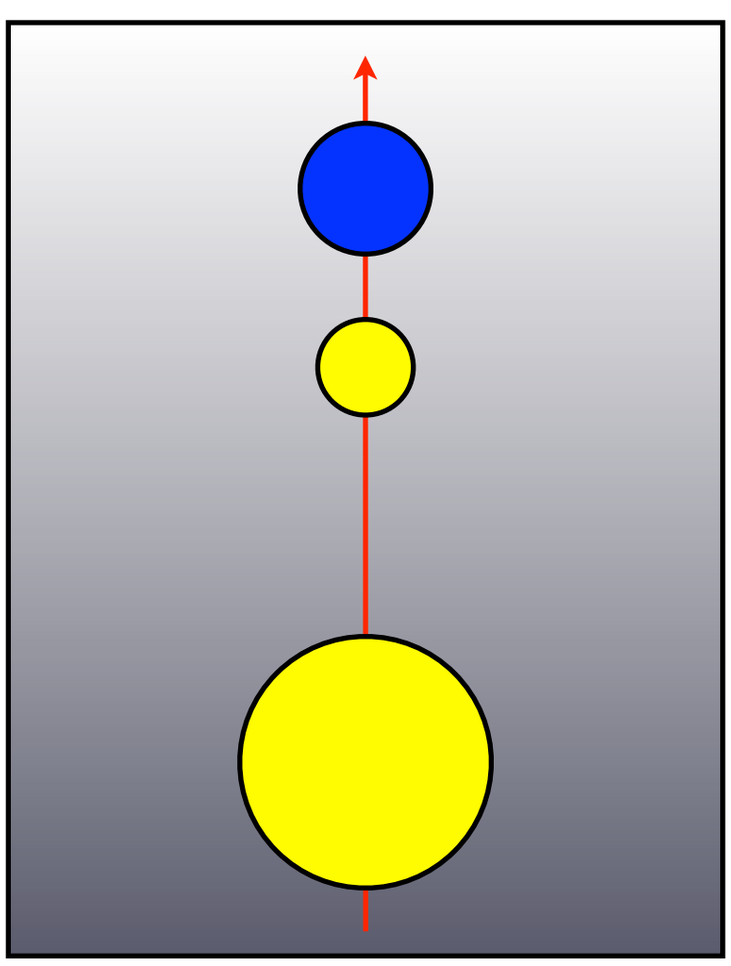
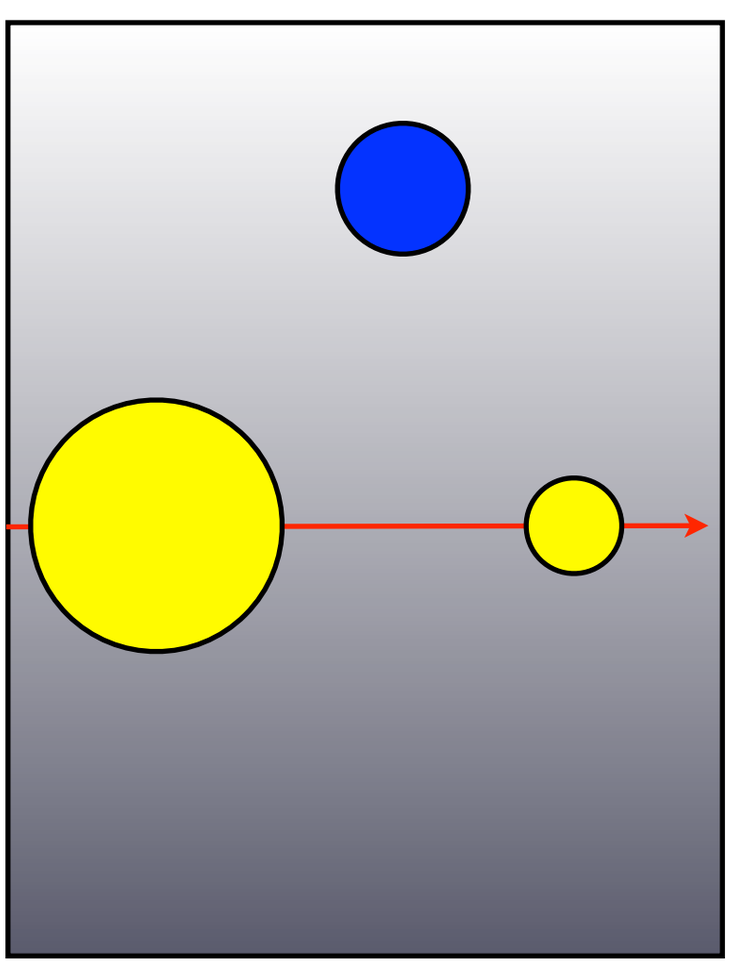
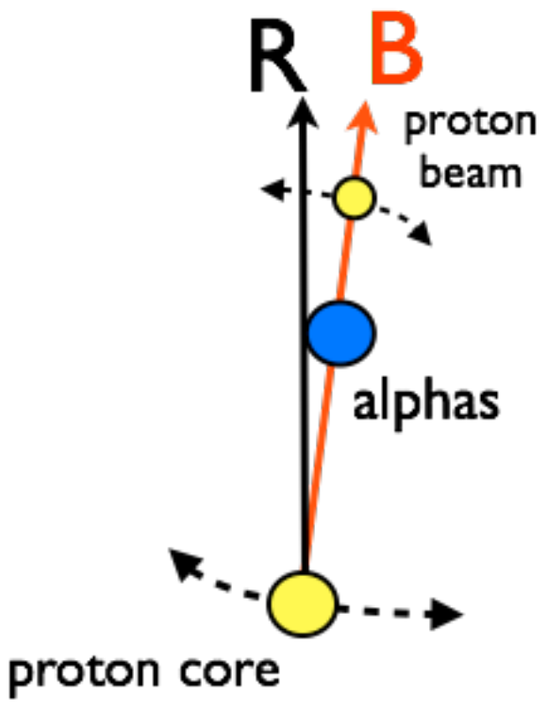
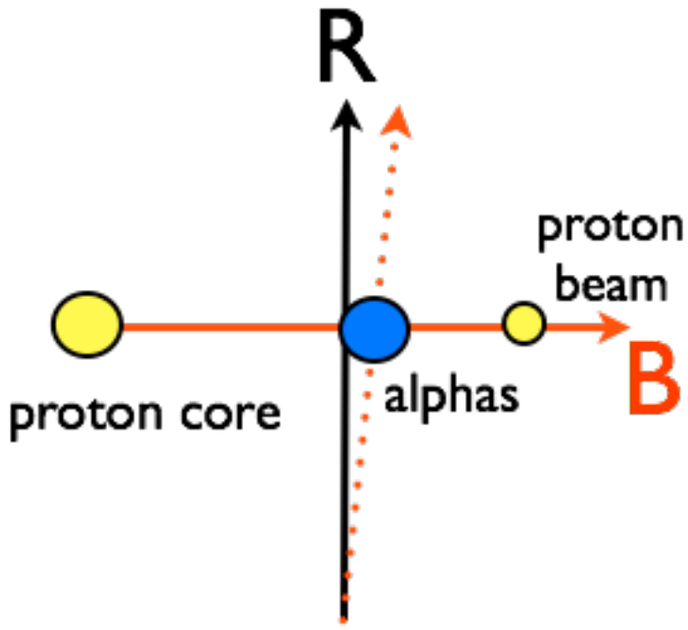
beam
B






R
B
proton
beam
alphas
proton core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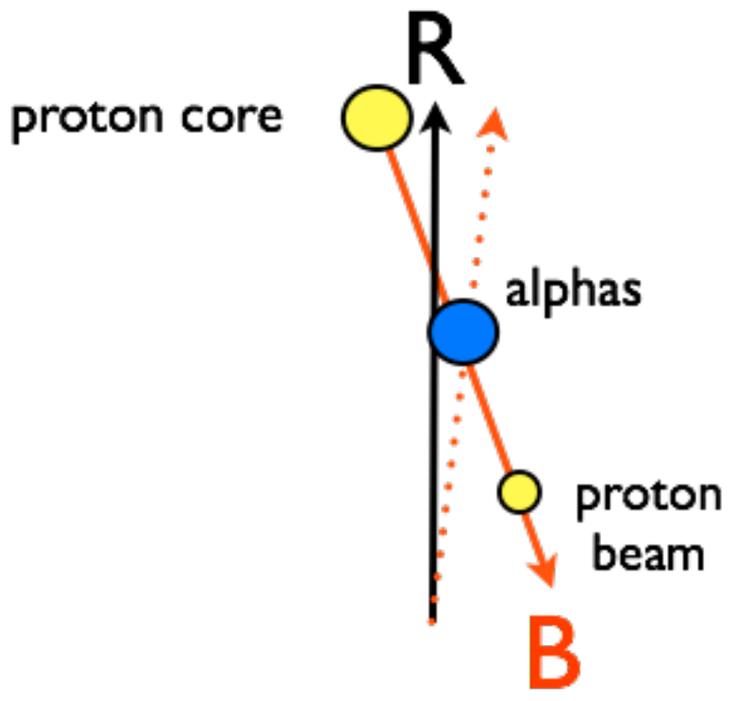
R
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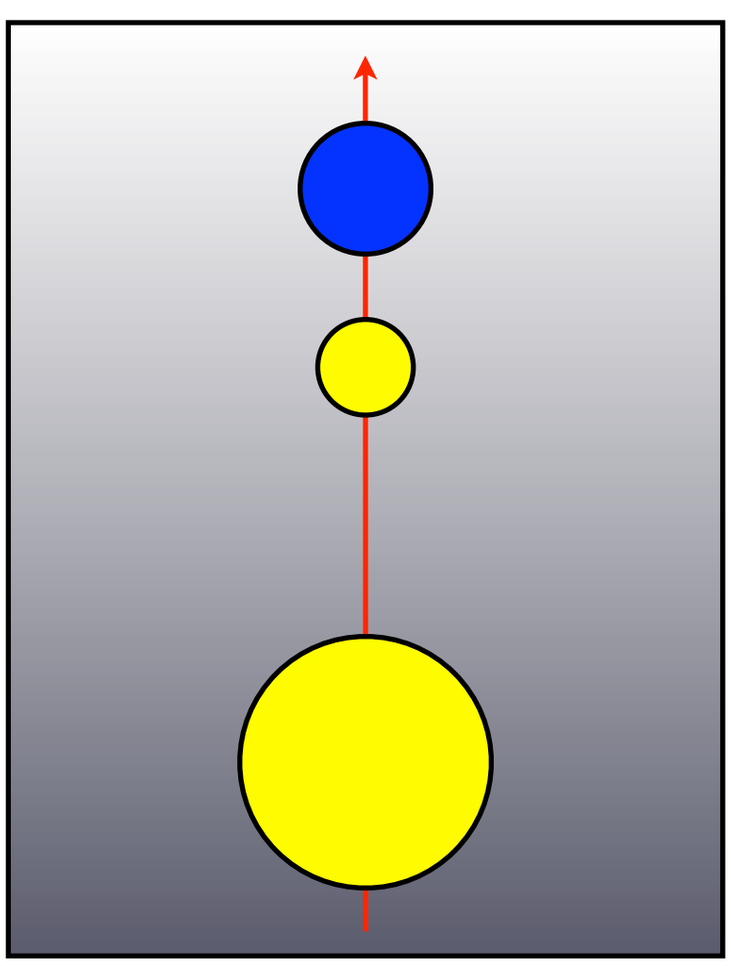

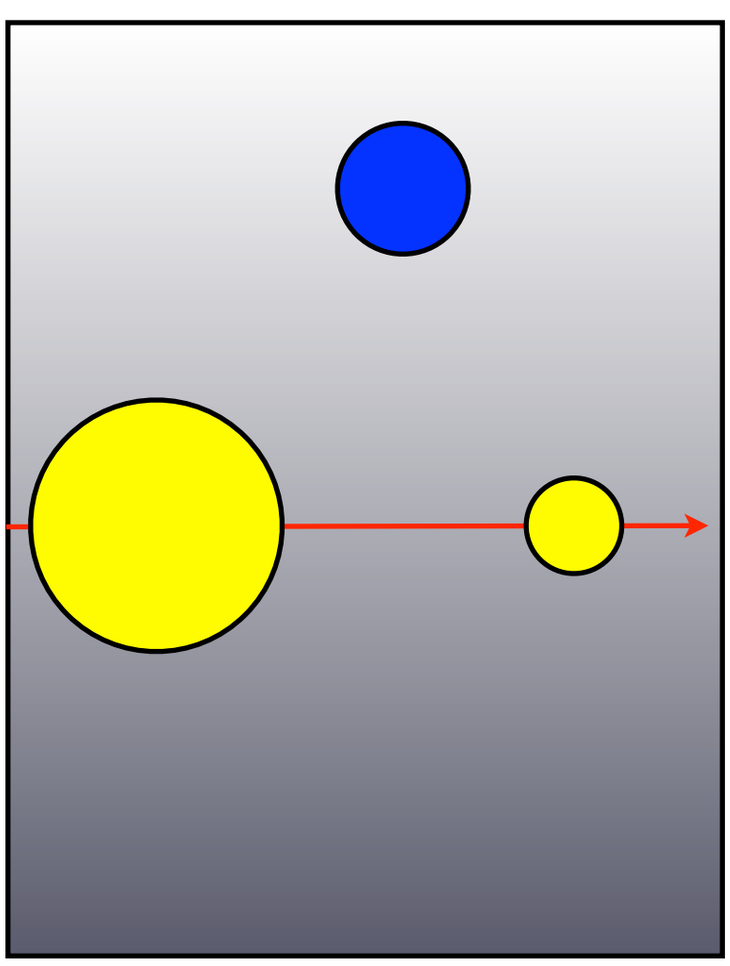

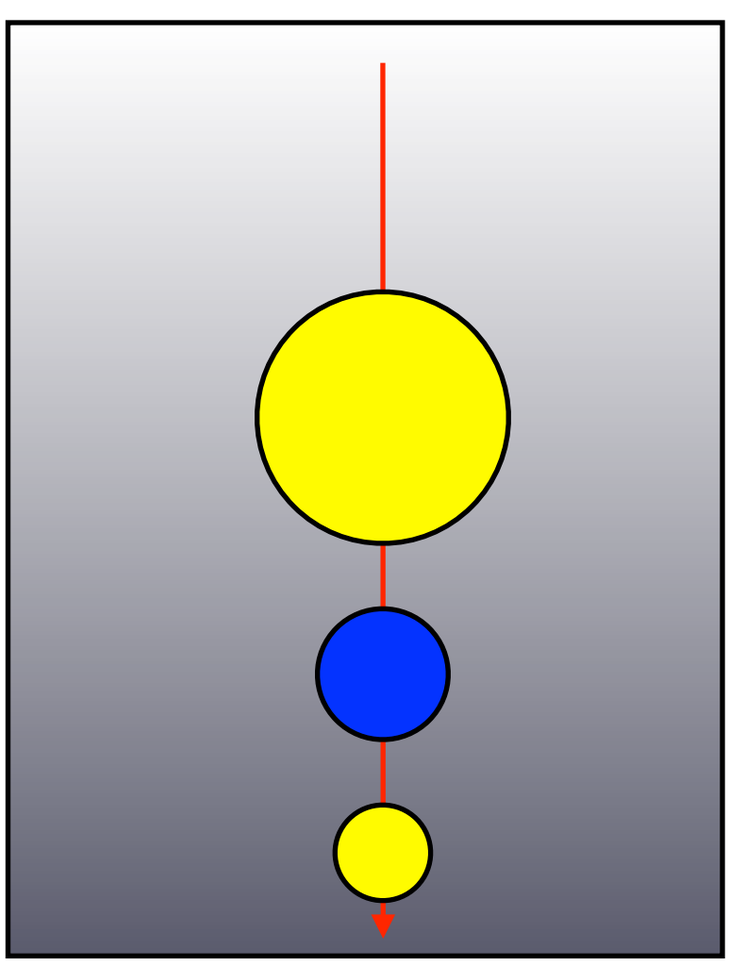

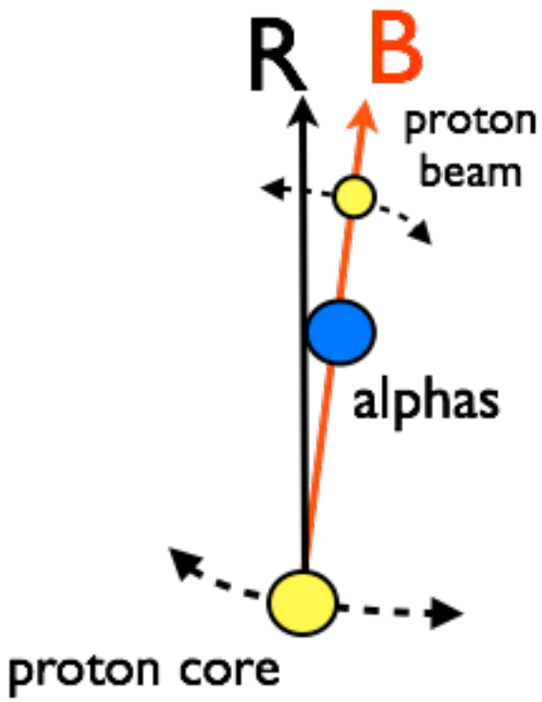
R
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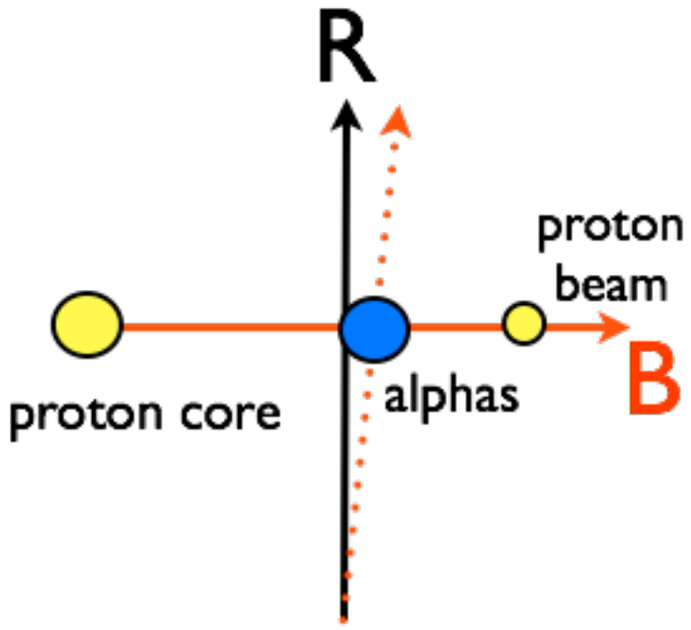
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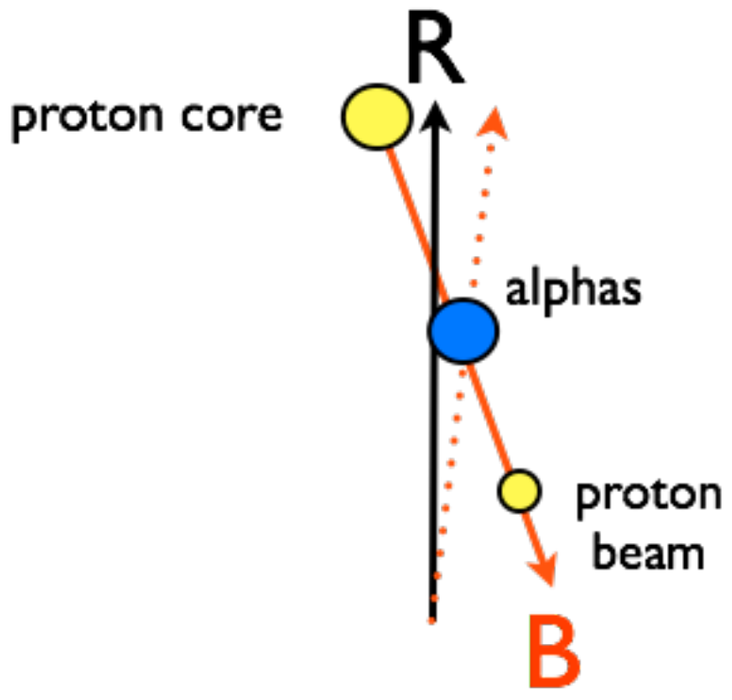
proton core
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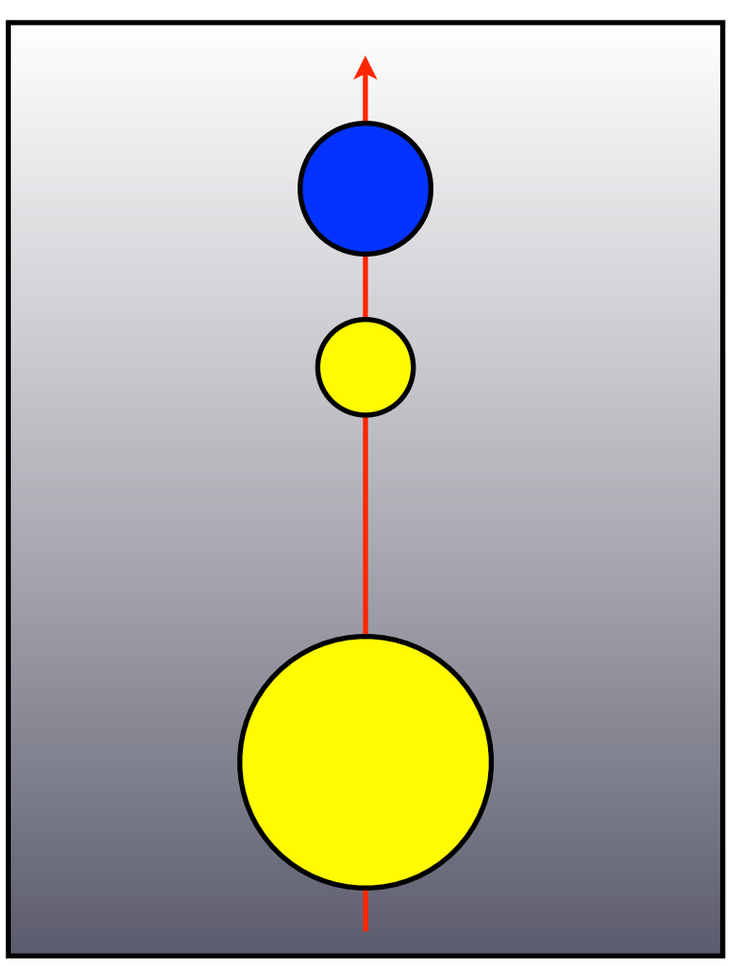
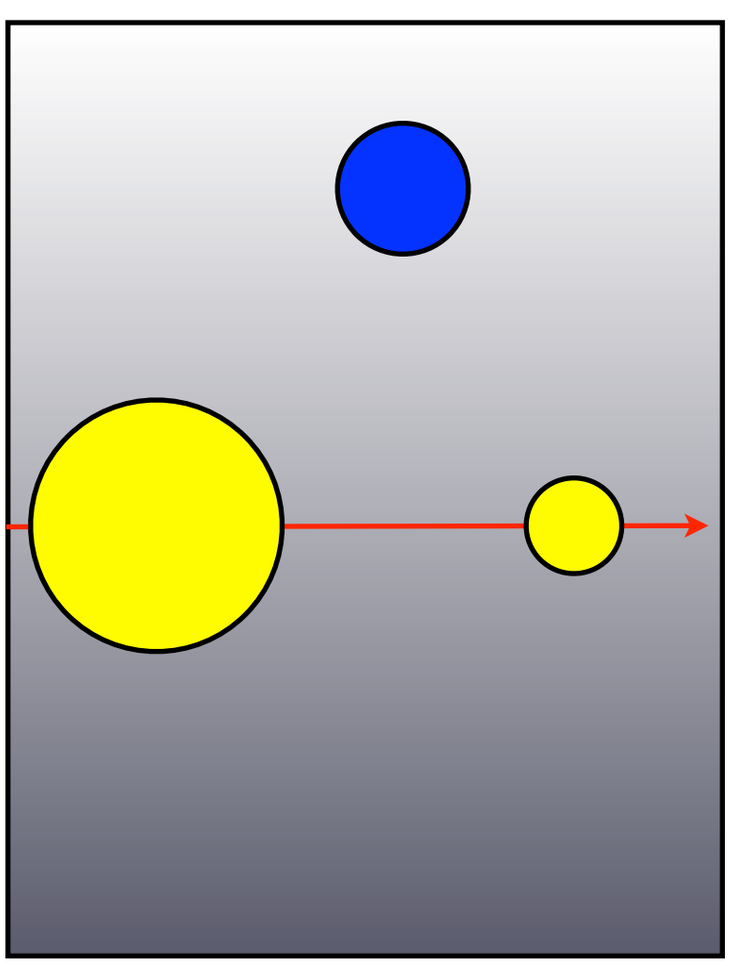
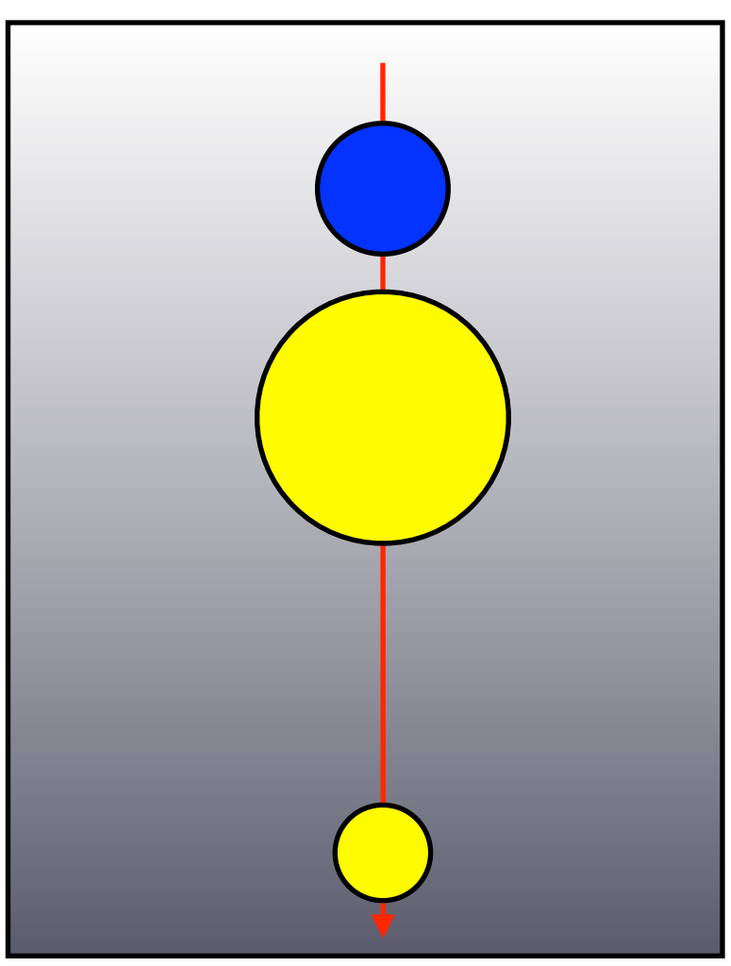
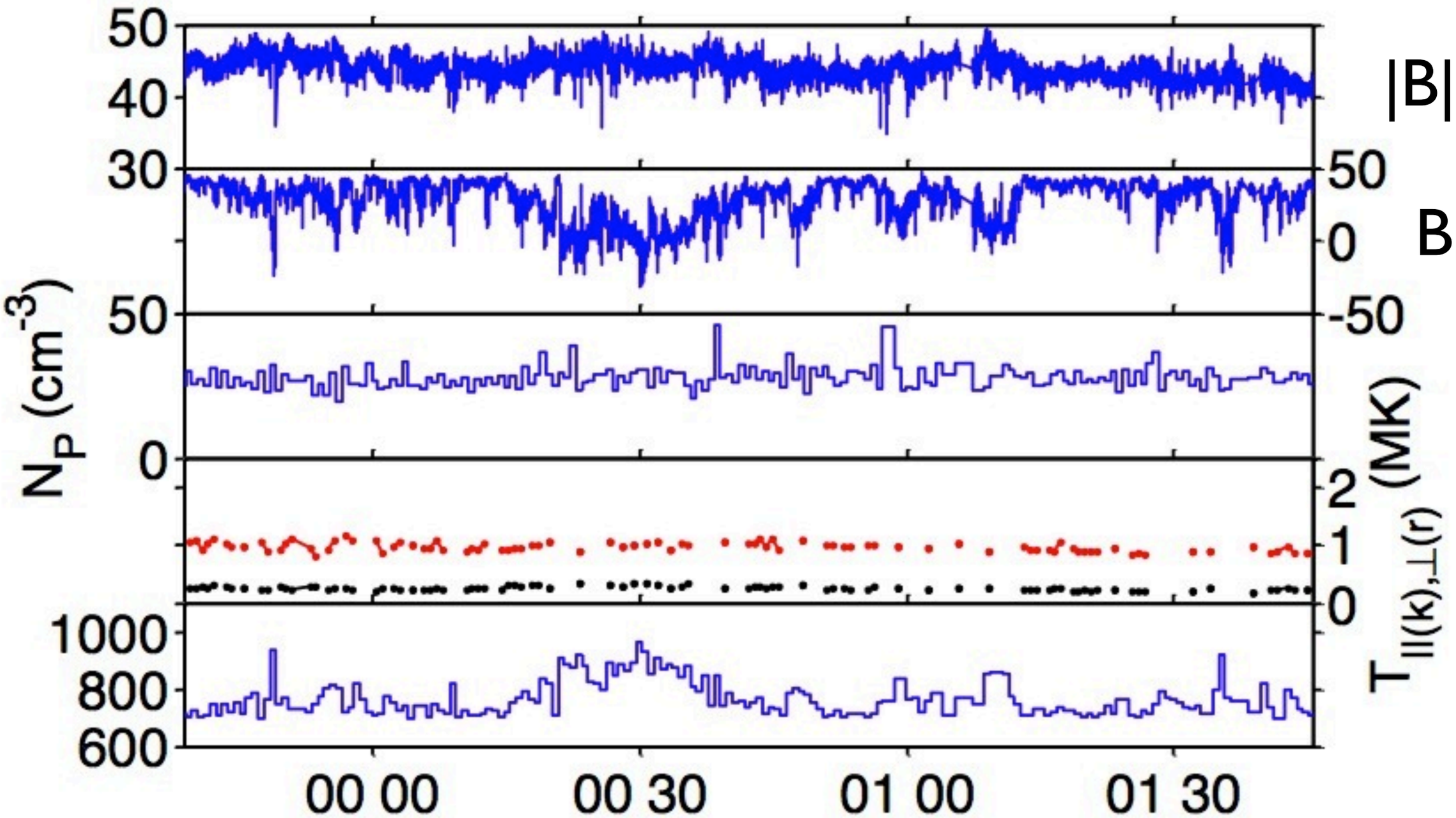






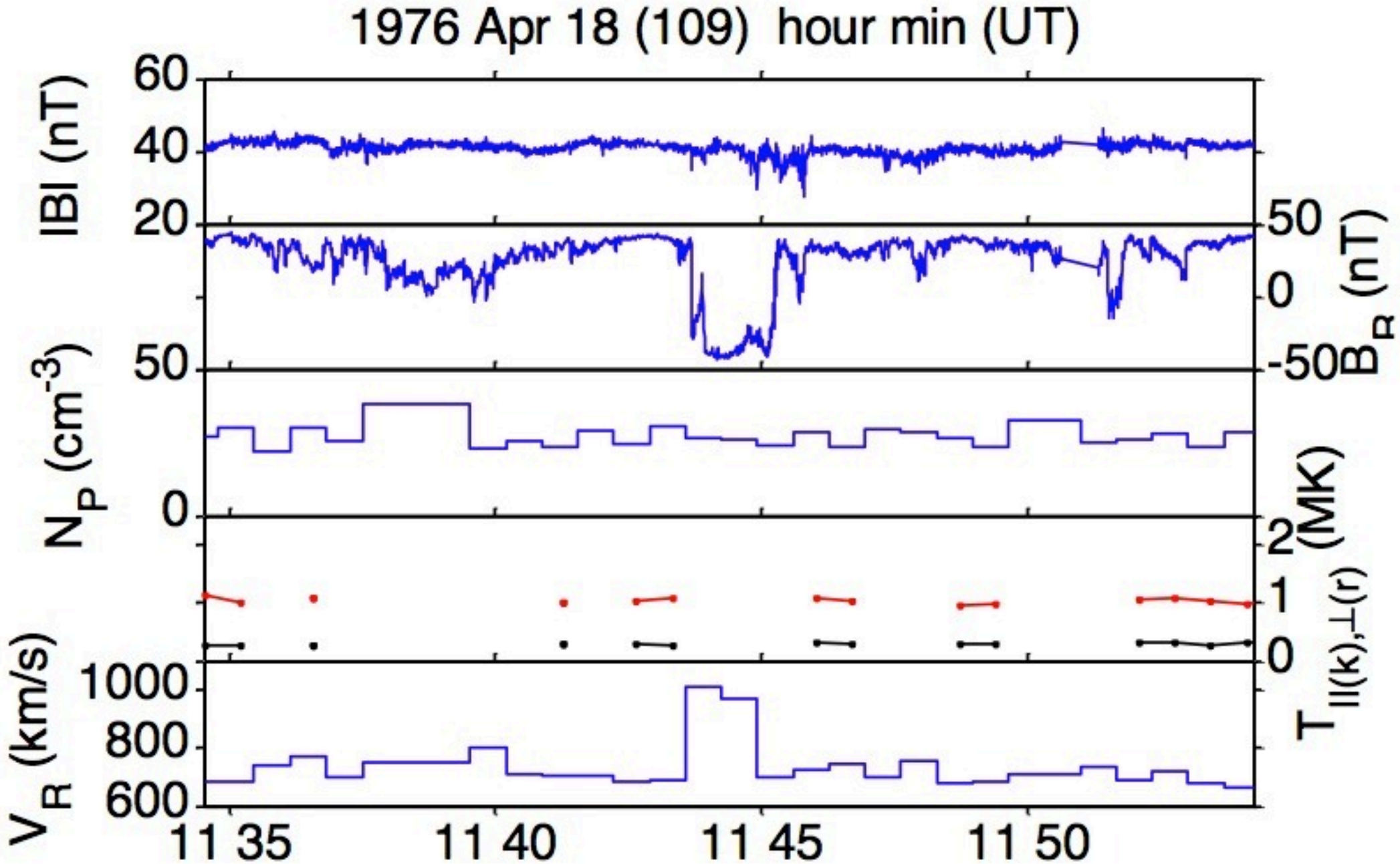
Helios: using B data at high res?



~2 hrs

Horbury & Matteini, in prep.

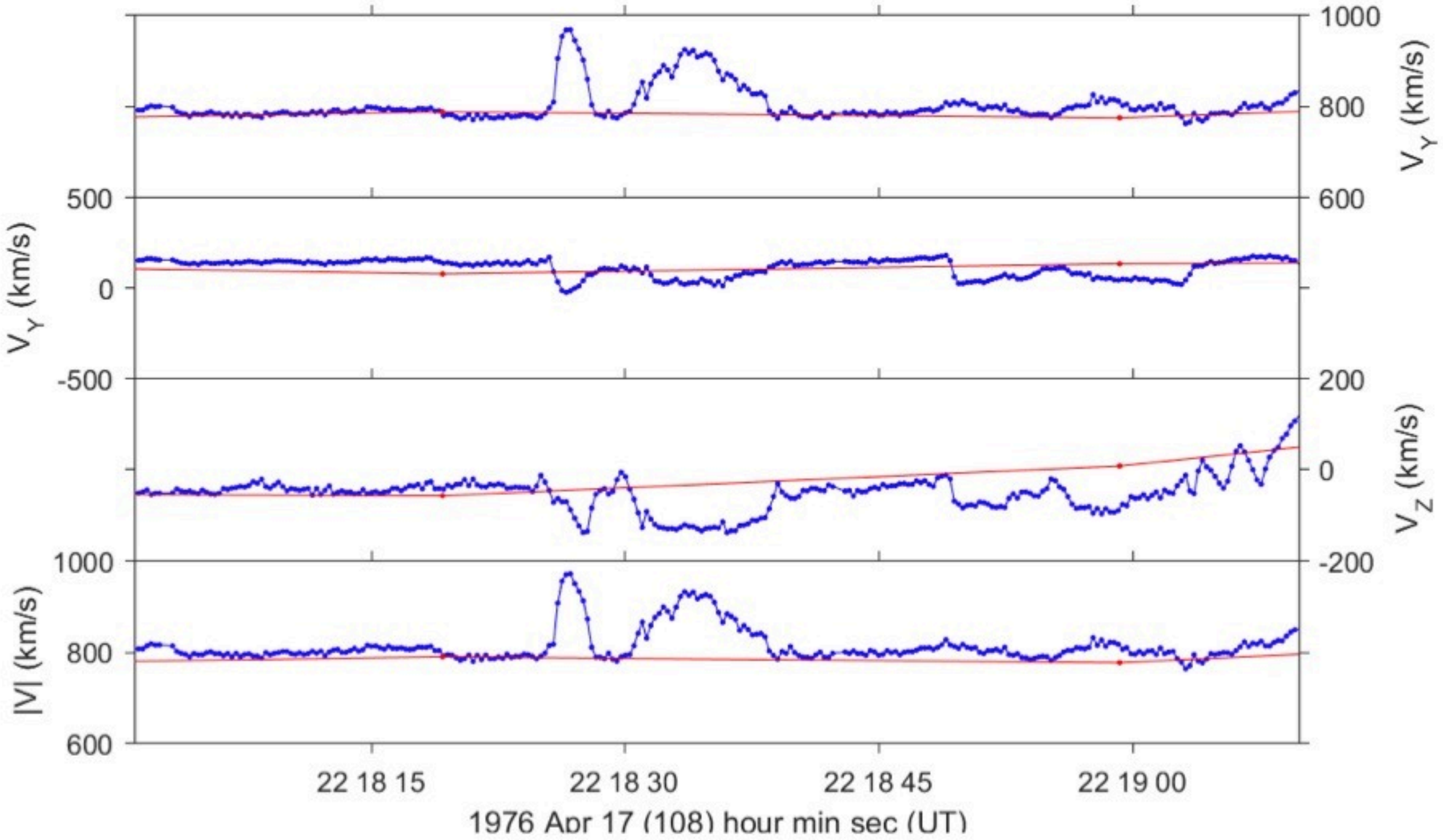
Zoom in on a velocity spike



~30 min

Horbury & Matteini, in prep.

Going beyond: use B data to reconstruct δV



~1 min !!

Horbury & Matteini, in prep.

Conclusion

- Helios data still offer us new results and unique view of inner Heliosphere
- Velocity enhancements up to 1000km/s at 0.3AU. Closer to the Sun? SPP...
- Short-living, high-resolution magnetic field show spikes of few seconds
- Consequence on particle measurements, VDFs are not trivial to fit during large B rotations
- Solar origin of spikes? Signatures of velocity shears in the corona? Intermittent SW acceleration?